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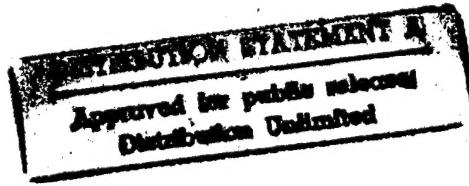
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Regional Technical Conference

Sponsored by

Quebec Section

Society of Plastics Engineers, Inc.

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QUEBEC SECTION

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## RIGID PVC FILM - ITS STATUS TODAY

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Consultant

Freeport, New York

### INTRODUCTION

Although polyvinylchloride has been around since 1872, high-quality, crystal-clear rigid films are a recent development. It has taken years to develop stabilizers to deter the thermal degradation of the resin enough so a suitable product could be obtained.

The terms "rigid" and "unplasticized" have been used frequently, sometimes apparently synonymously. The term "rigid" means that the formulation contains no more than ten per cent plasticizer. "Unplasticized" is reserved for those compounds which contain no plasticizer.

In a discussion of mechanical properties, Young's modulus may be a new term to some people. The modulus is a measure of the film's stiffness or rigidity. As the modulus increases, a thinner cross-section can be used to achieve the same amount of rigidity.

There are several impact tests that are used in the plastics industry: Charpy, Izod, falling dart and tensile impact are the most common. Falling dart impact test results have been quoted by some rigid vinyl film suppliers to support their claim of a product superior to other materials such as the cellulose esters. These figures are true but do not indicate the whole story. There are situations where the reverse is true. An examination of Izod impact data on a typical PVC-ABS blend shows one of the reasons why. Figure 1 shows that with notches of large radius and samples at room temperature, this material has excellent impact strength. However, as the radius and/or temperature decreases, the impact strength falls off sharply. When one examines the vinyl containers that fail, and their contents, it is usually discovered that the contents have sharp edges or corners that contact the film in a drop. These sharp points act as stress concentrators just as the notch in the Izod test does and cause failures at low load levels. This is not to say that this type of product cannot be packaged in vinyl. One very simple solution is to design the overall package so the product cannot act as a stress concentrator. While such innovations are most useful with highly notch-sensitive materials, such as PVC, they will also reduce package failures in other materials.

In the table that follows, a very few properties have been included. Other characteristics could also have been used. Color and clarity are always of interest to the potential user of a film. In certain applications, the effects of chemicals and solvents are paramount. It is too much to comment on all these. In general, it can be said that improvements have been made in the direction considered "good" in just about every area, although this sometimes means giving up

something in another area. Solvent resistance is often one of the first properties that is degraded when others are improved.

## MATERIAL

As mentioned previously, the vinyl chloride homopolymer is difficult to process because of limited thermal stability and high melt viscosity. The first rigid vinyl films were calendered from a vinyl chloride-acetate copolymer. The acetate content can be from 3 to 15 per cent. This type of film is still made today. It has no yield point; its tensile strength is high, and its elongation is very low. As would be expected, its impact strength is very low. Its oxygen transmission is about the same as that of film made from homopolymer, although the water vapor transmission rates are higher. It thermoforms well.

Much research has gone into developing stabilizers for polyvinylchloride. As a result, a film containing more than 99 per cent homopolymer resin is available today. This particular product can be used to package all foodstuffs in Canada but is only acceptable for federally inspected processed meats in the U.S.A. The yield strength is high, tensile strength is good, and elongation is surprisingly good. Its impact strength is better than that of the films made from acetate copolymers. The water vapor transmission rate is the lowest of all vinyl materials. Of all the vinyl films available, this one has the highest heat distortion point. The film will not distort until it is heated almost to the glass transition temperature ( $85^{\circ}\text{C}$ ). The exact temperature at which distortion will occur depends upon duration and magnitude of the load.

Although the impact strength of the polyvinylchloride is better than that of the copolymer, there are applications which require even more resistance to breaking. To improve the impact strength, additives called impact modifiers have been developed. To be a good impact modifier, the substance should have several features. Since loading rates under impact conditions cause the film to behave as if it were several degrees colder, the glass transition temperature of the modifier must be  $20^{\circ}$  or more lower than the service temperature of the film. To maintain the transparency of the vinyl, the modifier must be transparent. To eliminate haze and stress-whitening, the refractive indices of the base polymer and the modifier must be matched. Finally, the modifier must be sufficiently soluble in the polymer to insure good adhesion between phases but not so soluble that a two phase system will not develop. With these criteria, it is not surprising that there are not many impact modifiers for PVC available today.

One that is widely used in calendered and extruded film is ABS (acrylonitrile-butadiene-styrene). This terpolymer is used in quantities up to about 10 phr. Any further increase in concentration does not improve the impact strength of the blend. Film produced from a mixture of PVC and ABS has yield strength, tensile strength, and modulus lower than the homopolymer film. The elongation of both types of film are about the same. The impact strength of the film containing ABS will be better, especially below room temperatures. Water vapor is transmitted much faster through the impact-modified film.

Another impact modifier, MBS, is a terpolymer based in part on acrylic monomers. It is available from American and Japanese suppliers. The yield strength and Young's modulus of the MBS-modified films are closer to that of the homopolymer than to the ABS-modified films. The tensile strength is somewhat lower and elongation is significantly lower than the homopolymer, while both oxygen and water vapor transmission rates are higher. The impact behavior of the films

depends strongly upon which MBS is being used and its concentration. Too much of some grades of MBS actually lowers the impact strength of the film. There is supposed to be less stress-whitening of the film when MBS is used to improve toughness than when other modifiers are used.

While these modifiers are most frequently used with PVC, they can also be used with PVCA, and their effect on these properties is similar.

Vinyl acetate is not the only comonomer used with vinyl chloride. A new copolymer is made from vinyl chloride and propylene. It is claimed to be easier to process, to have greater stability, and to exhibit an excellent balance of properties. It is more readily extruded than PVC homopolymer. The data in the last column of Table I were obtained from tests on an extruded sheet of this material. Of all the materials, it has the lowest yield and tensile strength. Its modulus is comparable with the PVC-MBS blend and the elongation is in the middle of the range.

Other copolymers include those made with ethylene and vinyl cetyl ether. To my knowledge, no large-scale use of these materials in film has been made. The ethylene copolymer was first discussed at the SPE ANTEC in New York in May, 1968.

In general, the rigid PVC film available today is an excellent material for transparent packaging, exhibiting good mechanical strength, low permeability, and excellent color and clarity. In addition to the properties discussed in detail, the rigid vinyls have as a group other outstanding features. They are self-extinguishing and do not require additives to prevent burning. They are resistant to solvents, chemicals, greases, and oils. Rigid PVC will absorb very little water. Because the newer films do not have low molecular weight additives such as plasticizers, there is nothing to attack, craze, or migrate into the item being packaged.

Occasionally, however, an improvement in a selected property is desired. This improvement cannot always be obtained by formulation changes. As a result, laminations and coated films are being introduced for these specialized applications. Usually, the polymer being added to the vinyl film is either too expensive or is unsatisfactory in other areas to be used alone. By combining these films into a single product, the best of each component can be realized. Common combinations include: PVC and PE; PVC and Aclar (fluorohalocarbon); PVC, Saran and PE; PVC, Mylar and PE, and PVC and polyamide. The usual goal is to improve shelf-life by decreasing oxygen permeability and water vapor transmission. The subject of laminations would be a good topic for another paper.

#### THERMOFORMING

Once the rigid vinyl has been calendered or extruded, it is usually thermo-formed into its final shape. The same molecular architecture that gives PVC its desirable properties and its poor processability causes some difficulty in thermo-forming. Most vacuum formers are accustomed to cellulose esters which form very easily, can be used for deep draws, require only a moderate vacuum, and have a wide forming temperature range. When one starts working with vinyl, however, especially homopolymers, he is apt to be greeted by some combination of sagging sheet, incomplete formings (large bottom radii), holes in the sheet, long cycles, and webs. Unfortunately, the solution to these problems is not easy, although the causes are simple.

One feature of calendering is the low level of stress locked into the sheet - so low that the shrinkage of the sheet heated to 100°C is 2- $\frac{1}{2}$  per cent. It is often said that this stress level should be as low as possible. This claim is based on general experience with all extruded thermoplastic sheet. There is now evidence that it can be too low. When the strain is 5-7 per cent, the sagging is eliminated or greatly minimized. With the evidence now available, it would appear that this 5-7 per cent is optimum. If it is held constant, predistortion printing can be done and good registration maintained. The calendering houses are generally able to supply material with this strain level.

Another solution to the problem can be worked out by the former but should not be considered for production or anything except very shallow draws. It consists of screening the center of the sheet to prevent it from heating as fast. Since the ovens on most forming machines are hot in the center, this screening serves to even out the heat pattern. Sometimes sufficient screening to control sag means that the center of the sheet will be too cool for ideal forming. Then the parts will have a high stress level, or be incompletely formed.

A third alternative that has been proposed is to use female molds. This is not a cure-all and may even introduce greater difficulties in other areas.

Heating of the sheet is a very important step in forming PVC. As early as 1953, evidence of the importance of good sheet temperature control was published but not in terms of thermoforming. Figure 2 shows the amount of elongation to be expected as a function of temperature. The width of the peak, its height, and the temperature at which the maximum elongation occurs may vary from one formulation to another, but the phenomenon is always there. From this illustration, it is easy to see that even exact temperatures are required. As the depth of draw increases, the requirements become more stringent.

Designing a heater for a thermoforming machine is one of the hardest engineering problems in all of the plastics industry. All ovens in thermoforming use radiation heat. It is very difficult to analyze radiation systems and to apply engineering principles. To further complicate the problem, there is usually a large variable convection component which completely invalidates any computations that might have been made. The present heaters are the result of empirical design and evolution. Since most of the plastics sheet used until recently has had a wide forming temperature range, some of the shortcomings of the heaters were not discovered. PVC forming problems caused a re-examination of the heater designs and now another generation of heaters is coming out to cope with PVC.

The problem is to heat the sheet uniformly. If heating rods are evenly spaced across the span of the heater assembly, the center of the oven will get considerably hotter than the edges. One of the early improvements was to vary the spacing between the rods. The rods at the front and rear of the assembly were set closer together than those in the center of the heater. This improvement made it possible to form many materials all the way out to the clamp frame. When formers tried rigid PVC, they discovered that the center of the oven was still hotter than the edges. With some heaters, it was also discovered that the heater rods were too far apart. The film heated in strips. It was also difficult to heat the material within an inch of the clamp frame without overheating the rest of the sheet.

Recent changes in oven design include using more heater rods, using specially wound rods, and making the heater assembly larger. These changes have made several improvements in thermoforming PVC: cycles are shorter, the parts are better formed at the edge of the machine, and the sag is reduced somewhat.

There is a very simple experiment anyone can use to check the heat pattern of a forming machine oven. Cut a piece of corrugated cardboard to fit the clamp frame. Insert the cardboard into the machine just as if it were a sheet of plastic and heat the cardboard until it just begins to scorch. Remove the cardboard and examine the pattern of scorching. There should be uniform discoloration across the width and breadth of the board. There should be no streaks from individual heater rods. This is a rigorous test. Few heaters are perfect; however, gross nonuniformity should be avoided. It is easier to approach the ideal with a new machine by insisting on trials by the manufacturer. With existing machinery, it is much more difficult to correct heater problems. One can rebuild the heater, but this is costly and takes the machine out of production. Another approach is to use screening. As in the case of sag, this is an improvisation, but it is more valid in this application.

However, heater design is only half of the heater story. The temperature of the heater elements must be controlled accurately and uniformly. Presently, there are three types of controls in popular use: free running, percentage timers, and time proportioning thermocouple temperature controllers. Then there are three other types that deserve more attention, especially on machines running rigid PVC: radiation pyrometers, SCR thermocouple controllers, and variable transformers. Each has its advantages and disadvantages.

Free running heaters have no temperature controller. They are designed to run at a fixed temperature (140-160°F) upon application of the proper electrical voltage. This system is the least expensive and results in a constant infrared emitter. The design operating temperature is too high for some applications (it is possible to heat a sheet too fast). The actual temperature is affected by room temperature, line voltage variations, and (on moving heater machines) the length of time the heater is "home".

The simplest way to lower the temperature of the heater is to turn it off for a while. This is exactly what a percentage timer does. It turns the heaters off for a variable, reproducible time stated as a percentage of the time it takes the timer to make one complete cycle. This cycle is commonly 60 seconds. If the timer is set for 75 per cent, the heaters will be on for 45 seconds and off for 15 seconds. Percentage timers reduce the average temperature of the heater, but increase the actual temperature variation. They still do not compensate for line variations, room temperature changes, or heater rest time variations. In addition to the timer, an electrical contactor or relay is required.

From the timer, it is easy to go to the next type of control - a time proportioning temperature controller. Now a thermocouple, the controller, and the contactor are required. The thermocouple is mounted to sense a combination of the heater rod temperatures and the entrapped air temperature. This system compensates for the three variations not covered previously. It does allow some variation in element temperature. The exact amount depends upon the brand of controller and the location of the thermocouple. Incidentally, the indicating pointer on the dial of the controller cannot necessarily be trusted to give a true reading of the temperature variations of the heater.

Related to the time proportioning temperature controller is the SCR controller. It uses the same thermocouple, a different controller, and no contactor. It must be sized to the heater since no contactor is used. Instead of turning the electricity off when the set point is reached as the time-proportioning controller does, it reduces the amount of electricity until just enough is supplied to maintain a constant temperature. Very few forming machines have been equipped with this

type of control. They have been very popular on other types of machines where accurate temperature control is required. One big advantage is the maintenance of a relatively constant temperature on the surface of the heater rod, therefore, making the heater a stable infrared emitter.

The most sophisticated control system uses an infrared radiation thermometer (IRT). An excellent description of its use was included in Howell and Winton's paper at the 26th ANTEC in New York this spring. With the systems described previously, the temperature of the heater is controlled and the sheet is brought to forming temperature by regulating the heating time. The IRT measures the temperature of the plastics and adjusts the output of the heater and/or length of heating time. This is the only system that actually controls the sheet temperature. As such, it is the most desirable, but, alas, the most expensive.

The final system is variable transformers. These devices adjust the voltage supplied to the heaters. As the voltage is reduced, the temperature is also reduced. Such an arrangement means current is constantly flowing through the heaters, causing a constant level of radiation to be emitted. Line voltage variations still can affect the heater operation, although at a reduced level. Room temperature and heater rest periods are not compensated for with the transformers. The transformers appear to work best with quartz tube heaters but will also work well with the metal sheath style.

Since rigid PVC needs very accurate temperature control, it is imperative that one of the better systems be installed on any forming machine that is to be used to run vinyl. Figure 3 rates the six types of control for use with vinyl on two categories of machines. The single station machine is one in which the heater moves out over the sheet for a period of time, then retracts, and the sheet is draped over the molds. The in-line machine is one that provides for heating one section of the film while the previous section is being formed.

In the past, heater length to forming station width ratios of six to one have been advocated for in-line machines. Such ratios are as high as those required for foam materials. It is my belief that with proper temperature control, the ratio can be as low as two or three to one.

The best heater design and temperature control cannot cope with one gremlin frequently encountered in forming machines: stray air currents. One type of stray air current is the exhaust blast from an air valve. The heated sheet must be shielded from such blasts by installing baffles or by moving the exhaust mufflers to another location where the air cannot reach the hot film. Another source of air currents is found in some in-line pressure formers. The clamps or air cylinders holding the mold closed are not strong enough to oppose the air pressure used to form the sheet. As a result, the platen lifts slightly and allows air to escape. This air is cooler than the plastics and often blows back down the heater tunnel. These air currents cause random cooling of the sheet which in turn usually causes a distribution of holes in the formed part, or incomplete formings.

Once the sheet is heated properly, it must be forced against the mold. In vacuum forming, this is done by evacuating the space between the sheet and the mold and allowing atmospheric pressure to deform the softened plastics into place. At sea level, atmospheric pressure is 30 inches of mercury or 14 psi. The pressure available to deform the PVC is the difference between atmospheric pressure and the vacuum in the system. The vacuum in forming machines varies from 15 to 25 inches during drawdown. If the vacuum is 15 inches, only 7 psi is available to form the PVC. Rigid vinyl is very stiff at its forming temperature and requires all the

force the machine can muster. A minimum vacuum of 22 to 23 inches at drawdown is required. This calls for a high capacity, leak-free vacuum system. It also means the seal-off at the edges of the mold must be good. Evacuation should be rapid since the thin material will cool quickly and not form completely. A vacuum tank with a volume of 4-5 times the volume of the forming area coupled with an adequate pump will insure recovery between cycles, even if holes form in the sheet occasionally.

Webbing and bridging are two other problems encountered with rigid PVC. Little work has been reported on the optimum radii for molds to control webbing. One trend that is showing up is that these obnoxious folds of material can be eliminated in some instances by moving the molds closer together than would normally be done with the cellulose esters or other more familiar sheet materials. Drape assists also help eliminate the webs. If bridging occurs on the outer row of molds, it may be caused by material slipping out of the clamp frame. The solution, at the risk of over-simplification, is to ration the material available to each mold very carefully.

Since rigid vinyl has a higher modulus than the cellulose esters, one is tempted to go to a lower gauge for a particular forming. In some instances it might be better to use the same gauge but closer mold spacing. This will result in some combination of the following: the same wall thickness as the thinner gauge, less webbing problems, and less waste of material.

As is now apparent, the forming of rigid PVC calls for attention to the little details. With the right material, heaters, vacuum and mold design, rigid PVC will form as fast as its competitors. And the results will be a superior package.

## APPLICATIONS

Most of the rigid PVC film made today goes into packaging. Vinyl is very popular for the packaging of food and drugs because it combines excellent clarity, rigidity and barrier properties with FDA sanction. Packaging applications are not limited to the so-called FDA markets, however. Many manufacturers are packaging their products in blisters thermoformed of rigid PVC because of its good impact strength and cost. I would like to comment specifically on a few packages.

The first package is the one that evoked so much interest at the time of the introduction of the birth control pill. To produce this package, 5 to 7.5 mil PVC is thermoformed into a series of small blisters. A unit of the medication is put into each blister and an overlay of foil is sealed to the vinyl. This foil does not need to be peeled off, cut, or torn to remove the product from the package. The user pushes down on one of the blisters, forcing a pill through the foil. It is from this method of removing the product that the package receives its name: the push-through pack. In addition to its use to package The Pill, this design has been widely used for physicians' samples.

Processed meats, unlike fresh meats, need to have oxygen excluded. For this reason, rigid PVC has been used to package these foods. There are several versions of the coldcut package available in most supermarkets. In the last year, or so, some packers have switched from a straight PVC sheet to a laminated PVC in order to obtain improved barrier properties and better sealing characteristics. This application requires film that ranges from 7.5 to 20 mils in thickness.

Single-service packages are another major application of rigid PVC. These are 0.5 to 2 ounce containers for jellies and coniments served in restaurants and institutions. Most of the cups are made from 7.5 mil clear film and covered with foil or flexible vinyl. A new addition to this product line is a 2-ounce container of cocktail sauce or ketchup. One manufacturer calls it the "Dippin' Cup".

There are, of course, non-packaging applications. The most familiar of these are Christmas trees and ornaments. Stress-whitening tapes are made from a vinyl that may be described as borderline between rigid and flexible.

No paper on PVC is complete without mention of the bottle. Thermoforming techniques have been developed for producing colorless PVC wide-mouth bottles from calendered or extruded sheet. The jar is made from two halves and connected by spin-welding. The seam adds rigidity and is covered by the product label.

The future of PVC is in applications requiring a clear stiff material. It is true that uses exist where opaque pigmented vinyl is used. Often, however, other films are better and cheaper in pigmented applications. PVC homopolymer is in abundant supply. The film deserves more attention by package designers and engineers for applications where its special qualities are important.

#### SUMMARY

Someone has said that PVC is the original engineering thermoplastic. It does possess an outstanding set of properties. The rigid vinyl available today is a superior product. It has better color and higher impact strength than the vinyl available less than a decade ago. The total set of properties it has makes it more desirable than many other materials with which it competes. When thermoforming PVC, even, accurately controlled heat and a good vacuum are required. Imaginative packaging is the greatest application for these materials.

#### ACKNOWLEDGMENTS

Several film producers very kindly supplied samples of their films for testing so the comparisons of the various materials would be valid. The laboratory personnel at Stauffer Hoechst Polymer Corporation ran the tests on all the films. Dr. Shoulberg of Rohm and Haas supplied Figure 1.

TABLE I  
SELECTED PROPERTIES OF RIGID 10 MIL VINYL FILMS

Base polymer Impact modifier	PVC None	PVC ABS	PVC MBS	PVCA None	PVC-PP ?
Method of processing	Calen.	Calen.	*Extr.	Calen	*Extr.
Specific gravity	1.397	1.335		1.351	1.310
Yield strength ( $10^3$ psi)	7.8	7.0	7.7	N.Y.	6.5
Tensile strength ( $10^3$ psi)	5.6	5.2	5.1	9.5	4.7
Young's modulus ( $10^5$ psi)	6.1	5.2	5.7	7.0	5.6
Elongation (%)	95	93	20	0	44
Izod impact					
Oxygen transmission <sup>1</sup>	10.5	10.9	13.2	10.2	15.5 <sup>4</sup>
Water vapor transmission <sup>2</sup>	2.6	6.8	7.8	5.2	4.5 <sup>4</sup>
Forming index <sup>3</sup>	1.44	1.28	1.04	0.89	0.90

<sup>1</sup>cm<sup>3</sup>/24 hr.m<sup>2</sup>.atmos.

<sup>2</sup>gm/24 hr • m<sup>2</sup>

<sup>3</sup>sec./mil for complete form

<sup>4</sup>extrapolated from 18 mil sheet

\*Data given in verbal presentation

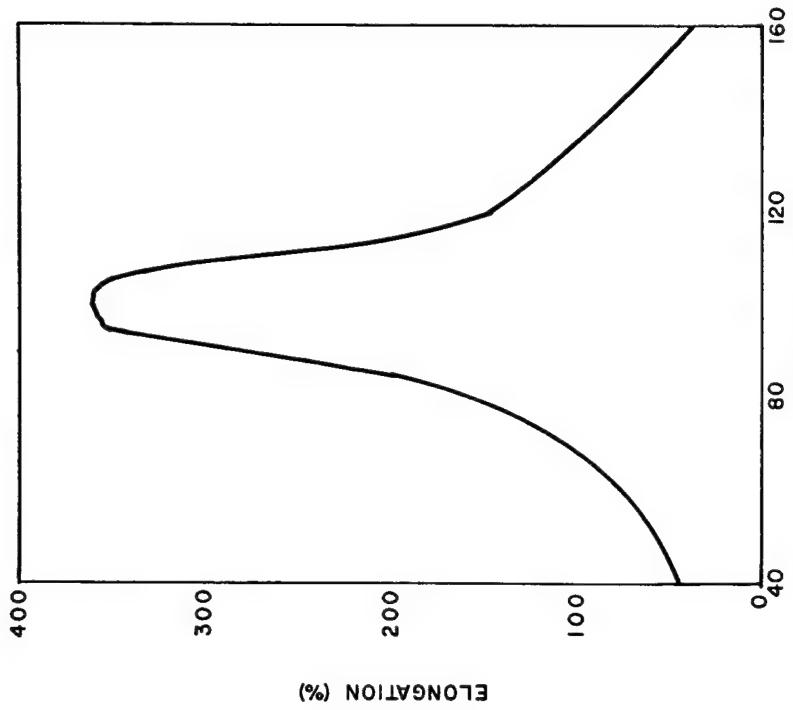


FIGURE 2: Elongation of Rigid PVC

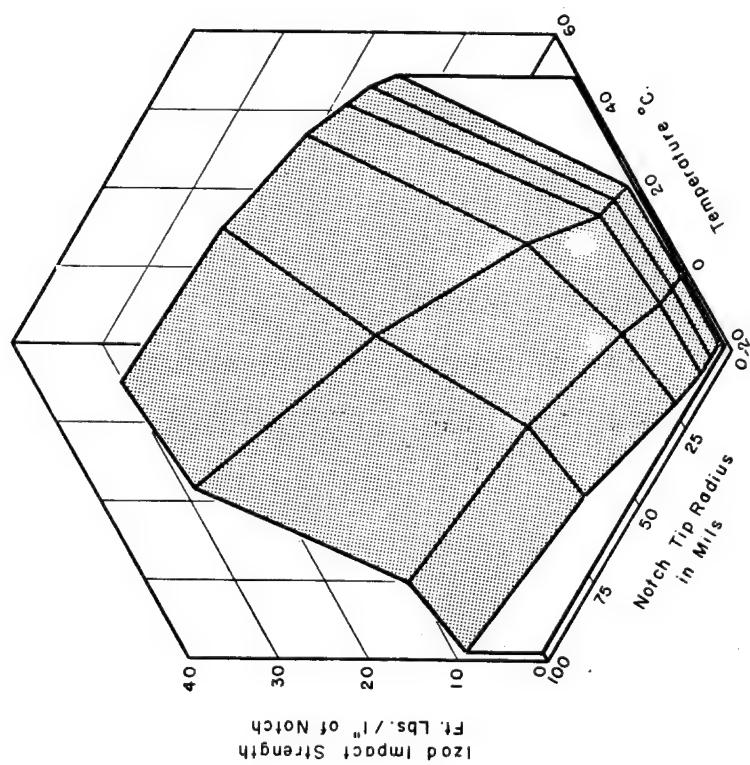


FIGURE 1: Effects of Notch Tip Radii and Temperature on Izod Impact Strength of ABS-Modified Poly (Vinyl Chloride)

Type of Control	Single Station	In-Line
None	P	P
Percentage Timer	F	P
Time Prop. T.C.	G	F
Variable Transformer	F	G
SCR T.C.	E	G
IRT	E	E

FIGURE 3: Ratings of Temperature Controls

## THE LINK BETWEEN TEXTILES AND VINYL-COATED FABRICS

P. Dan O'Kray

Vinyl Operations

Ford Motor Co.

### INTRODUCTION

Principles of polyvinyl chloride technology can be joined with traditional textile technology to produce knitted vinyl - a material possessing the favorable wear and colorfastness of vinyl and breathability exceeding textile seating fabrics, together with excellent tailorability.

### BACKGROUND

Vinyl-coated fabrics have enjoyed a phenomenal growth in automotive seating.

Originally, sateens were utilized as a backing fabric because of their high strength. Broken twills, having higher stretch, replaced sateens as backing fabrics when tailoring the sateens became a problem. Knitted backing materials were finally adopted to increase the ease of tailoring without substantial strength reductions.

These developments in tailoring properties were unseen by the automobile purchaser. The colorfastness and wear resistance of vinyl seating became well known, but many felt that conventional textiles were more comfortable. Recognizing this, research efforts turned to "breathable" vinyls. Most of the developments in breathable vinyls were of a rather limited utility since many properties generally inherent in vinyl were sacrificed in the process. Knitted vinyl, however, was developed as a breathable vinyl incorporating the favorable aspects of textiles and vinyl-coated fabrics.

Simultaneous slitting and knitting from a flat sheet is a patented process. Originally intended for knitting paper for the meat processing industry, the process has mushroomed to include knitting of polyvinyl chloride and other thermoplastic films. A prime economic advantage of the slit-knit process is that film is slit and knit in a single operation, obviating any need for multiple processes of yarn preparation - slitting the film into narrow strands and winding the strands on bobbins - before knitting.

Subsequent processing techniques have been developed to convert the raw knit into material suitable for seating. Several patent applications are being filed with respect to the finishing operations.

## SLIT-KNITTING

A special polyvinyl chloride film formulation, developed for end application requirements and for "knitability", is calendered to very close thickness tolerances. Before slit-knitting, the calendered roll must first be cut into pancake-shaped rolls about 5" wide. Slitting and Knitting are two phases of a single operation. Vinyl stripped from the "pancake" is slit into a number of narrow strands (usually one strand per inch of knitting cylinder diameter) in the "Ekon-O-Vrt" (Enterprise Mfg. Co.) phase of the operation. A thin coating of lubricant helps to prevent needle breakage and drag on the material through the knitting machine.

Each strand of vinyl, usually 1/8 inch wide, is fed to a knitting station. There is generally one knitting station for every  $\pi$  inch of cylinder circumference. At the knitting station the strand will be folded in half along the longitudinal direction of the strand. Reinforcing yarn may be inserted within the folded strand, or, for that matter, may be "plated" on the surface, to increase the strength of the product. The strength of the product can easily be magnified when the proper synthetic reinforcing yarn is added. For example, the following tensile strengths were noted on knitted vinyl in which the only variable was the nature of the reinforcing yarn:

<u>Knitted Vinyl with:</u>	<u>Tensile Strength, lbs.<sup>1</sup></u>
	<u>Wales/Courses</u>
No reinforcement	35/40
100 denier nylon	67/81
210 denier nylon	95/120

Conventional circular knitting machines are used in the knitting phase of the operation. The knitting stations are stationary and evenly spaced around the circumference of the knitting cylinder; the cylinder and the windup rotate counter-clockwise. As material leaves the knitting cylinder it is forced into the form of a flattened tube and then wound on a tubular core.

Generally, circular knitting machines designed for knitting such yarns as cotton and nylon, must be modified to accommodate the heavy knitted vinyl - the raw knit may weight up to 50 ounces per square yard.

The knitting cylinder contains several "cuts" in the outer circumference into which the knitting needles are inserted. A "five-cut" cylinder signifies that there are five needles per inch of circumference; the resultant knit goods produced thereon will be relatively coarse. As the number of "cuts" increase, the distance between the stitches decreases, and smoother textures are obtained. Thus, material produced on an eight-cut cylinder will have a smoother texture than that produced on a five-cut cylinder.

Each knitting station consists of a yarn feed, a raising cam, a stitch cam, and a pattern wheel (see Figure 1). A knitting needle will either "knit" or "tuck" at a knitting station. There is always at least one loop on a knitting needle. If the needle rises to such a height that the loop clears the needle latch, that loop will be knit off when the needle descends with the new strand (see Figure 2). If the needle should rise only to a point such that the needle fails to clear the needle latch, the loop will be "tucked" when the needle descends with the new strand (see Figure 3). Now, when the needle begins to ascend at the following knitting station, there will be two strands on the needle.

The pattern wheel governs placement of the needles into a knit or a tuck position. A number of slots are cut into the outer circumference of the pattern wheel in such a manner that the butts of the needle, extending out of the knitting cylinder, mesh with the slots in the pattern wheel. If jacks are placed in the pattern wheel slots, the needles will be forced to rise to the knit position. If no jacks are placed in the pattern wheel, the needles will be forced into the tuck position - a level lower than the knit position.

Usually a pattern wheel will contain both unfilled slots and slots filled with jacks; thus, specific needles may be made to knit or to tuck at a given knitting station.

The mechanism at a knitting station consists of the following:

- (1) The raising cam acting on the needle butts raises all the needles to a height where the needle butts will mesh with the pattern wheel slots;
- (2) The pattern wheel jacks or the absence thereof, will place each needle in either a knit or a tuck position;
- (3) The stitch cam acting on the needle butts causes all needles to descent.

While the needles are descending, the needle hooks are taking up the feed strand and either knit off or tuck the strand already on the needle.

By controlling the knit-tuck cycles through which a needle passes at each knitting station, the overall stitch pattern will be determined. In producing material for the 1969 Ford Motor Company products alternate slots in the pattern wheel are filled with jacks, and a needle passing four knitting stations will be forced to knit twice and then tuck twice. The cycle is repeated over each four knitting stations. This stitch is sometimes denoted Le Costa. Although it is difficult to graphically represent the Le Costa stitch pattern when the bulky vinyl strands are knit, Figure 6 demonstrates how the Le Costa stitch pattern would look if cotton yarn were used. Each machine produces about twelve yards of material per hour. "Stop-motions" stop the machine if a rupture should occur in the vinyl strand or the reinforcing yarn.

Width of the knit is a function of reinforcement (if any); stitch pattern; number of cuts in the cylinder; cylinder size; strand width; and strand thickness. There is also a tendency for the width of the tube to decrease as the material ages in the roll. Although the theoretical width at knitting should be ( $\pi$ ) (cylinder diameter), the actual width, if the tube is fully opened, is only about 80 per cent of the theoretical width in the case of knitting 1/8 inch strands incorporating 200 denier reinforcing nylon and knitted in the Le Costa stitch pattern on a five-cut cylinder.

#### SUBSEQUENT PROCESSING

Since material leaving the knitting machine is in a tubular form, the first post-knitting operation is a longitudinal slitting of the tube and opening the material into a sheet. The tube could also be double-slit into two narrower sheets if desired.

Knit goods in the raw state possess many undesirable properties detrimental

to commercial appeal. During knitting, stresses are incorporated into the material. The stresses are manifested by a tendency of the material to curl when opened into a sheet. Several post-knitting processing methods are the subject for patent applications on file. The end result of the processing is a product having a pleasing "hand" and appearance, satisfactory strength properties, and soil resistance. A topcoat imparts uniform gloss and a dry, non-tacky feel to the surface.

## STYLING

A prime attribute of knitted vinyl is its versatility from a styling viewpoint. Many concepts inherent in textile styling are applicable to knitted vinyl.

Two or more colors may be combined by use of multiple films at the knitting machine. By rearranging the color order of strands passing to the knitting stations, several color combination patterns are available to the stylist.

Another styling variable lies in the overall stitch pattern. By varying the knit and tuck order which a needle performs, an unlimited number of stitch patterns are available, each having a unique appearance. It is possible to knit geometric designs into the material as well as altering the background effect. Texture is an important feature to the stylist, and, as mentioned previously, is a function of the "cut" of the cylinder. The stitch pattern, to a lesser degree, also affects the texture of the goods.

Another styling possibility would include selective insertion of a metallic yarn into the material by plating over a vinyl strand or substitution for a vinyl strand. In addition to the styling concepts indicated, and combination thereof, other innovations develop as familiarity with knitted vinyl increases.

## PROPERTIES

In general, it may be stated that knitted vinyl combines the most favorable qualities of textiles with those inherent in vinyl. The comfort of textiles as seating during hot summer months is generally conceded by vinyl producers. "Comfort" is a nebulous feature not readily capable of measurement by laboratory instruments. In the final analysis, comfort so far has been determined only by human reaction to the material. Extensive field tests have proved that people find the material cooler and more comfortable during hot summer months. (Many claim that the knitted vinyl actually "heats up" more quickly during the winter than vinyl-coated materials). Several truck drivers in the hot Arizona climate stated that knitted vinyl was the most comfortable seating material they had even encountered.

Although comfort factors may be incapable of precise laboratory measurement, it is generally recognized that porosity, or ability of a material to pass air, is a factor related to comfort. Knitted vinyl far surpasses any form of seating material in current automotive use (see Figure 4). Although porosity of knitted vinyl varies with the type of stitch, etc., it is of such a magnitude that it will remain far above other automotive seating fabrics.

Another indicator of the comfort of knitted vinyl is the fact that the material is also receiving acceptance in office furniture. Office workers sit on the material for much longer periods of time than automobile drivers and are, in a

sense, in a better position to evaluate "comfort".

It was shown, supra, that knitted vinyl can be made as strong as desired by use of the proper reinforcing yarn. Knitted vinyl currently in use was developed to meet the stringent strength requirements placed on automotive seating. The table below illustrates the basic physical requirements of automotive vinyl seating in terms of evolution from vinyl-coated sateens to knitted vinyl:

	Tensile <sup>1</sup> Strength (minimum) W/F	Trapezoid Tear Strength (minimum) W/F	Stretch <sup>2</sup> W/F	Set W/F
Vinyl-coated sateen (spec.)	117/108 lbs	7.0/7.9 lbs	1-5/4-8%	0-2/0-2
Vinyl-coated broken twill (spec.)	117/103 lbs	8.0/9.0 lbs	1-5/6-12%	0-1/0-3
Vinyl-coated 6.7 oz. cot- ton jersey (spec.)	117/100 lbs	20/20 lbs	8/30% min.	25% of stretch max.
Automotive knitted vinyl (spec.)	90/110 lbs	25/45 lbs	35/35% min.	25% of stretch max.
Automotive knitted vinyl (typical results)	95/130	30/50 lbs	50/35%	12/10% of stretch

It can be noted that, although tensile strength requirements have been relatively constant, tear strength requirements have been upgraded in the evolutionary process. Field tests have indicated that nonreinforced knitted vinyl should have sufficient strength for most seating applications.

The above table is also illustrative of the developments in tailoring properties of automotive vinyl fabrics, as indicated by stretch values. It has been shown that there is a constant tendency toward seating materials having increased stretch properties for ease in tailoring. Being a knitted construction, knitted vinyl has stretch characteristics which lend to easy tailoring. The material can be shaped over mild contours quite readily. Unlike vinyl-coated cotton jersey, there is usually more stretch in the wales direction than in the courses direction. Set values, indicative of recovery properties, are comparable to most coated knitback constructions.

One of the most lauded properties of vinyl seating is its abrasion resistance. Knitted vinyl retains this desirable quality. In Figure 5, test specimens of automotive body cloth containing nylon yarns and of knitted vinyl are illustrated after being subjected to a rigorous abrasion test. Each specimen was abraded for 400 cycles on a Taber Abrasion Tester with H-18 wheels and 1000 gm. loads. Although it is doubtful that any material would be subjected to such severe abrasion in actual service, the test is a good illustration of knitted

vinyl's wear qualities.

Colorfastness of vinyl has generally been recognized as one of its most favorable properties. Knitted vinyl, of course, also possesses this quality; dyed textiles cannot claim such a high degree of colorfastness.

When knitted vinyl was first evaluated, there were fears that the material would unravel after a rupture occurred, as by puncture with a sharp instrument. The fears proved groundless - subjecting the material to blows from an ice pick resulted in the ice pick seeking out a pore in the material. When the ice pick was removed, the "hole" remaining tended to "repair itself" with no evidence of the "hole" remaining. Subjecting conventional vinyl or upholstery fabric to this type of treatment would, of course, leave a noticeable hole which might tend to act as a site for tear propagation.

Knitted vinyl apparently can be handled in the same manner as other fabrics. It can be sewn and, unlike textiles, dielectrically sealed. Decorative effects, as well as piece-to-piece joining may be accomplished by dielectric sealing of knitted vinyl.

#### CONCLUSIONS

Knitted vinyl possesses the most beneficial attributes of conventional textiles and of vinyl-coated fabrics. Breathability of the product, related to comfort, exceeds that of other seating materials. Colorfastness and abrasion resistance of knitted vinyl is that traditional to vinyl-coated fabrics.

Styling variations through use of two or more different colored films, or by imaginative designs in stitch patterns, are features formerly limited to conventional textiles. Use of metallic yarns provide additional styling versatility.

Control of knitting variables and processing techniques result in a product that can be designed to meet specific strength requirements. A cost in the area of conventional textiles, plus the comfort picture of the product, should make knitted vinyl competitive with textiles used for seating purposes in both automotive and furniture upholstery.

#### REFERENCES

1. American Society for Testing Materials, Method D 751-52T.
2. Ford Laboratory Test Method BN 4-1; Standard Test Methods, Vinyl Fabrics Institute.

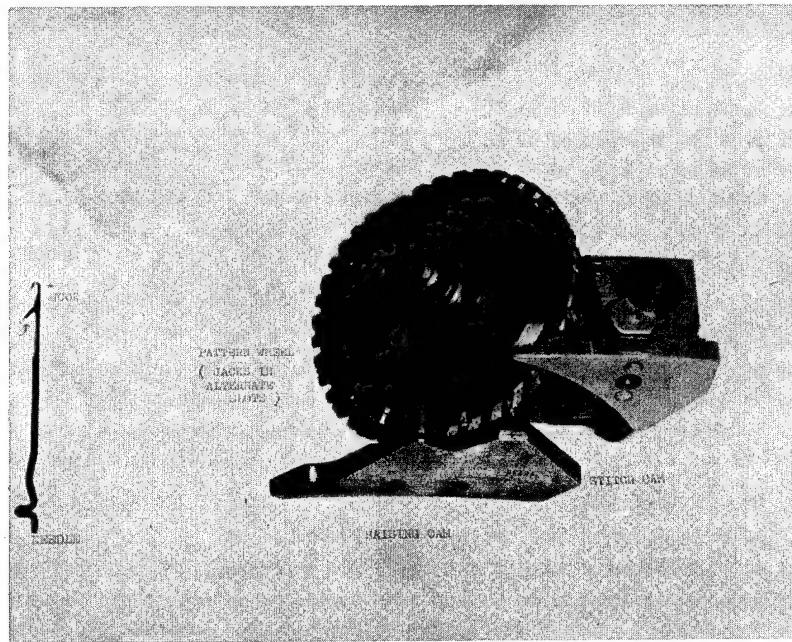


FIGURE 1: Basic parts to a knitting station

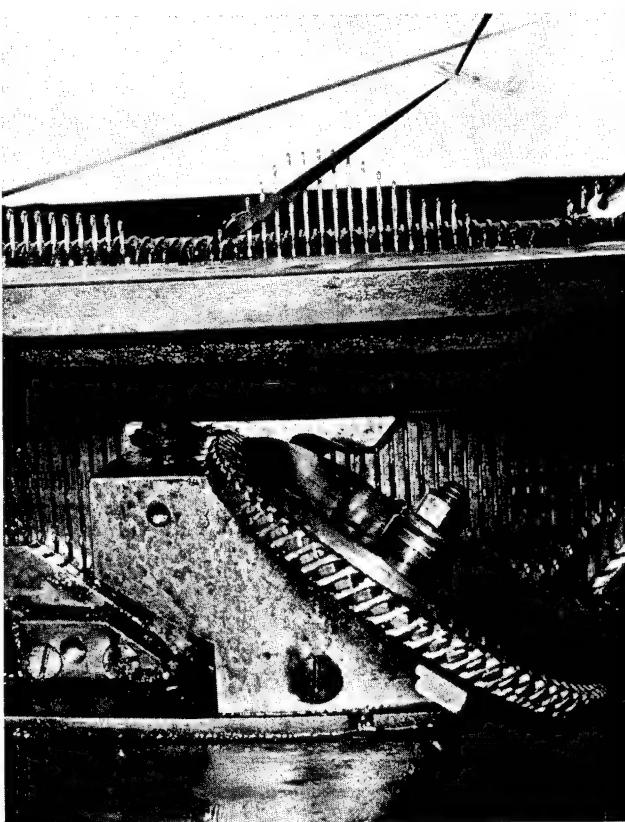


FIGURE 2: Formation of a knit stitch. Note jacks in pattern wheel causing needles to rise to "knit height". (Folder removed to better illustrate needles).

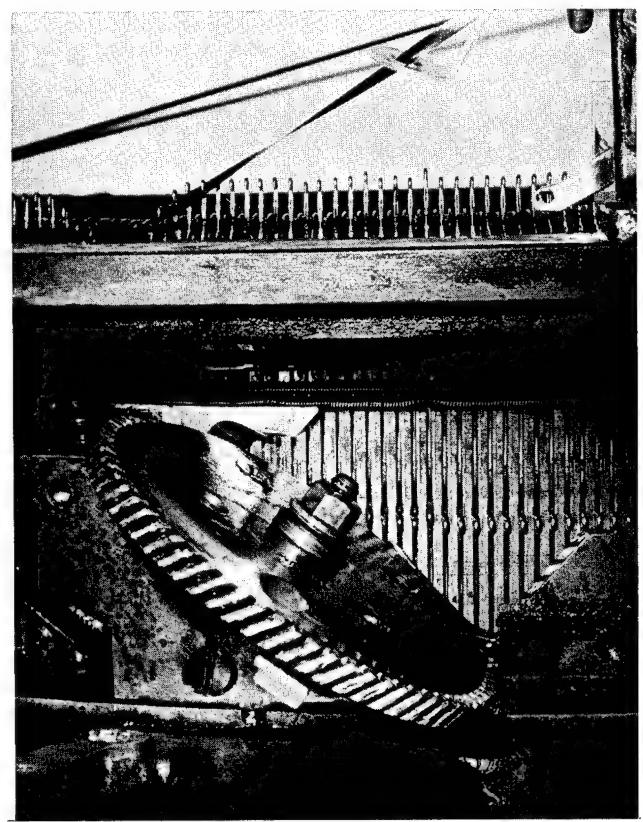
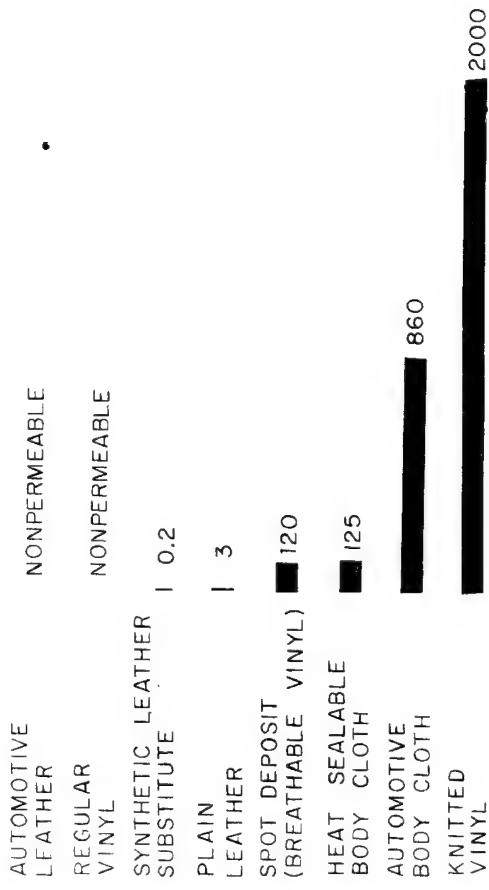
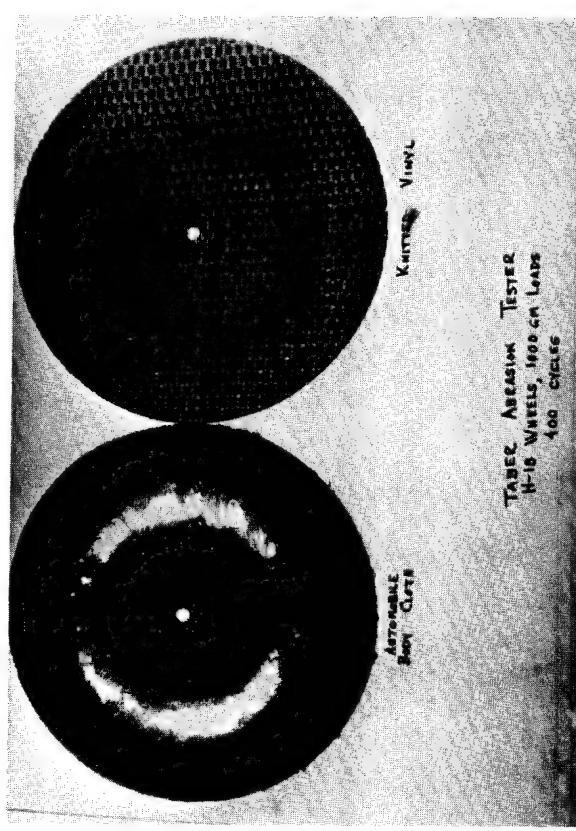


FIGURE 3: Formation of a tuck stitch. Note that height of needles lower than in knit stitch. (Folder removed to better illustrate needles).

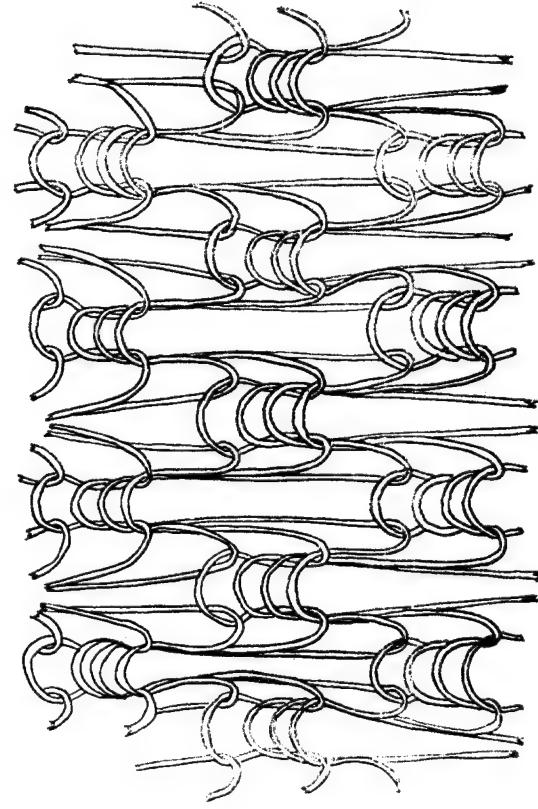
## RELATIVE POROSITY OF SEATING MATERIALS



**FIGURE 4**



**FIGURE 5: Relative abrasion resistance of body cloth and Knitted Vinyl.**



**FIGURE 6: Representation of Le Costa stitch in cotton.**

UNIFORM GAGE AND REDUCED ORIENTATION IN PLAIN AND EMBOSSED SHEET  
WITH IMPROVED DIES AND CONTROLS

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#### INTRODUCTION

*L* Plastics sheet processed for embossing, thermoforming or shapes, be it rigid or flexible sheet, should leave the lips of the die at a uniform pressure, constant melt temperature, gage thickness desired and minimum orientation.

This paper will cover melt temperature, its effect on quality and a new approach to extruder control based on melt temperature; plus sheet die design based on minimum residence time and orientation for the extrudate.

*(author modified)*  
It is the writer's opinion that these two areas, melt temperature and die design, can be applied to the full range of thermoplastic and put into practice can accomplish much toward quality production.

Uniform pressure of the extrudate being directly related to the type of resin and extruder screw design will be left to others.

Quality requirements in embossed or plain plastics sheet extrudate can vary and in some cases, specifications are very exact and demanding as to the final product which is acceptable. Not only is the end user interested in the appearance of the embossed sheet or the shrinkage of his thermo-formed product, but the ultimate customers are also showing more interest in the service life of his plastics product. Basic resins are now available on the market which are greatly improved over those offered in the past years and much of this advancement is due to better additives in the form of UV absorbers, plasticizers, anti-oxidants, etc., plus technical knowledge as to their properties. The spectacular growth of plastics resins has, in a large part, been due to the development and good performance of chemical additives in compounding these resins.

The mechanisms of additive behavior in the many resin applications are not fully understood by many of the additive suppliers, let alone processors one or more steps down the line. (Plastic Additives 68: State of Art Report by Louis Naturman, Managing Editor, Plastics Technology, July 1968). Quantities of the above additives in the basic resin are very important and it becomes essential that the extrusion process be capable of producing an extrudate which retains these

components as supplied by the resin manufacturer, if quality of a finished product is to be acceptable. Since degradation of any of these additives is hastened by heat, time, or a combination of the two, it is only common sense to process any resin at a minimum melt temperature and as short a residence time in the equipment as possible.

As an example: A very common UV absorber as used with polystyrene resin has a melt point of approximately 130°F. It is, therefore, essential that such a resin be extruded at a low melt temperature and minimum residence time in the die if the required quantity of the additive is to be retained in the extrudate. Often it is possible to extrude a resin at a much higher melt temperature if residence time is shortened and the process then becomes a balance between temperature and time. As a safe measure, the producer is going to be in a better position if the melt temperature is controlled and the flow of extrudate after leaving the extruder is handled in the adapter and die with a minimum of stagnation, and uniform velocity in the flow.

Recently at the 1968 SPE ANTEC in New York, a paper entitled "Melt Temperature Control System" was presented by Mr. Glenn Pettit of Barber Colman Company, co-authored by Paul Ahlers of Johnson Division in which a new concept of extruder control was introduced (Figure 1). This system is based on the premise that precise control of steel temperature is not the critical thing for plastics extrusion. Instead, a control system that controls the most important variable, the melt temperatures, and which influences heating and cooling of the extruder barrel steel as necessary. The prime advantage of this melt temperature control are the features that the operator can:

1. Change his through-put rate and have constant melt temperature. He adjusts the screw RPM for pounds per hour and the melt temperature control system will increase the heating or cooling of the extruder steel barrel as required.
2. The operator can change the melt temperature to suit the process requirements by setting only one control point instead of the usual 4 or 5 zone barrel controls as commonly found on the extruder.
3. The automatic reset to change the zone controller set points, obtains a straight line temperature reading on the extruder barrel which is very similar to results obtained by a proportionate current controller.

The operator control (Figure 2) one dial, is located in the potentiometer recorder and capable of 1°F resolution, is set for melt temperature. Controllers for each extruder zone are preset and the per cent effect adjustment on each zone allows individual zone tailoring. It may be advantageous to manipulate the feed zone less than the transition and metering zones, or the opposite, depending upon the screw and material characteristics. The per cent effect feature of the system gives the user the ability to preset the amount of suppression from the melt temperature in order to change the barrel temperature profile - usually down - so that a minimum change occurs at the feed zone with maximum change appearing at the metering zone. Provision is made to check the barrel steel temperatures at any time by flipping a switch and reading the dial of the pyrometer.

It should be noted that this melt temperature control system will not compensate for incorrect screw design or faulty resin which may cause short term variations in the melt temperature. Practical operation of the control system in

the field has proved its value in blown film production, shapes and contour and it shows great promise in many areas where melt temperature is a critical item. Details of this control system are explained more fully in the SPE Technical Papers of the 1968 ANTEC.

To further process the extrudate which we have produced with a controlled melt temperature, it is recommended that it be formed into a sheet with a minimum of resident time in the adapter and die.

The performance of the standard sheet die with its large area manifold section and various components which are assembled into the bulky piece of equipment, has been accepted in the past (Figure 3). This type of die has been used very extensively in the production of sheet even though no attempt is made to streamline the flow areas and no thought is given to the degradation of the resin or its additives. The construction of the die with its squared off lip face does not lend itself to production of sheet in which the present practice of three-roll polish or embossing and cooling rolls are used. The distance from the lip discharge to the nip of the roll is often 8 to 12 inches and the effect is a neckdown of the plastics sheet and extremely high orientation. Improvement in flow areas is shown in Figure 4. The teardrop configuration of the manifold and elimination of the secondary manifold has the effect of greatly reducing the extrudate residence time. The front lip design has also been revised to permit moving the lip discharge closer to the nip of the rolls. This type of heavy-duty die has proven itself in gages .375" and heavier. It is considered an excellent die; however, there are many areas of sheet production, principally in the lighter gages of .001" to .030" where the Flex Lip(R) die has proven itself (Figure 5). The flex lip design shown in Figure 5 has adjustable lip opening ranging from .001" to .030" thickness. Its construction with the 45° angle on the discharge face enables the die lips to extrude the plastics much closer to the nip of the rolls of the polish-cooling unit. The necking down of the extrudate is held to a minimum and the orientation is greatly reduced, (a very important item to the post operation of thermoforming). In some cases it is possible to reduce the air gap from die lip to nip of the rolls to within 2-3", depending upon the roll diameters. Adjusting of the die lip opening is accomplished with adjustment bolts on 1" centers and accounts for accurate gage of thickness across the sheet. Flexing of the lip is limited to a maximum movement of .030".

Original design of the manifold section and plastics flow areas of this die have been changed and revised over a period of years due to experience in the laboratory and field operation of extruding heat degrading resins. Those flow areas in the die which showed signs of stagnation and degraded resins were reduced in area until through trial and error method a final design arrived at had a profile which had uniform flow of material. This die, due to its ability to produce excellent results with rigid vinyl, can be used on more stable types of resins with better than usual results and a minimum of resident time. The die constructed in two major parts does not have a separate adjustable lip, restrictor bar and end plates. Consequently to clean the die is a very simple operation of separating the half sections and because of its clean design in the flow area a simple task of removing the plastics slug results in a clean die ready for assembling. Normally, the die can be cleaned and put back in service in less than 15 minutes. Note the clean exterior lines of the die body.

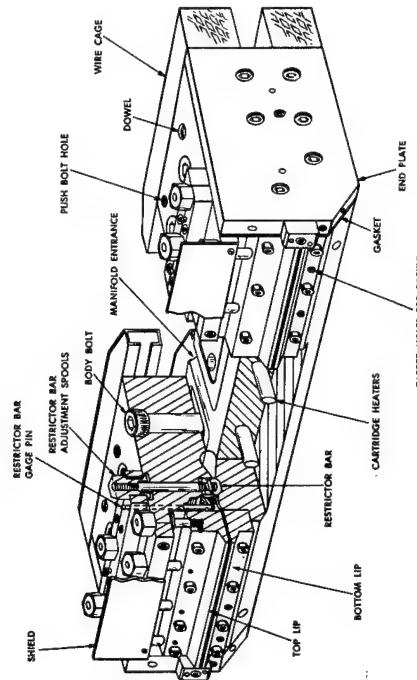
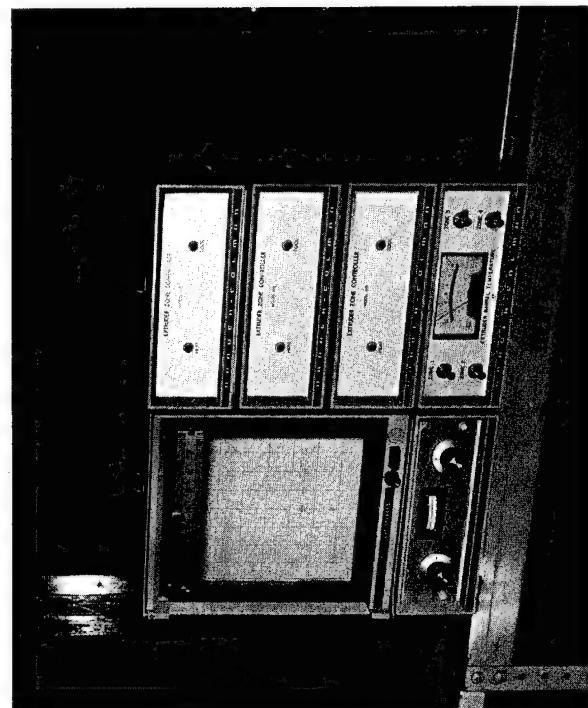
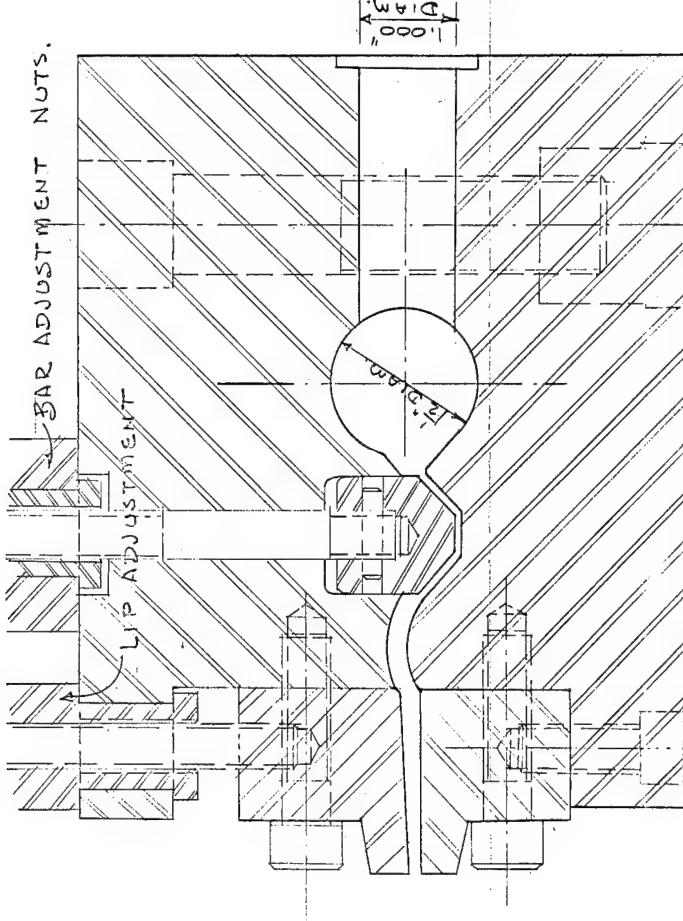
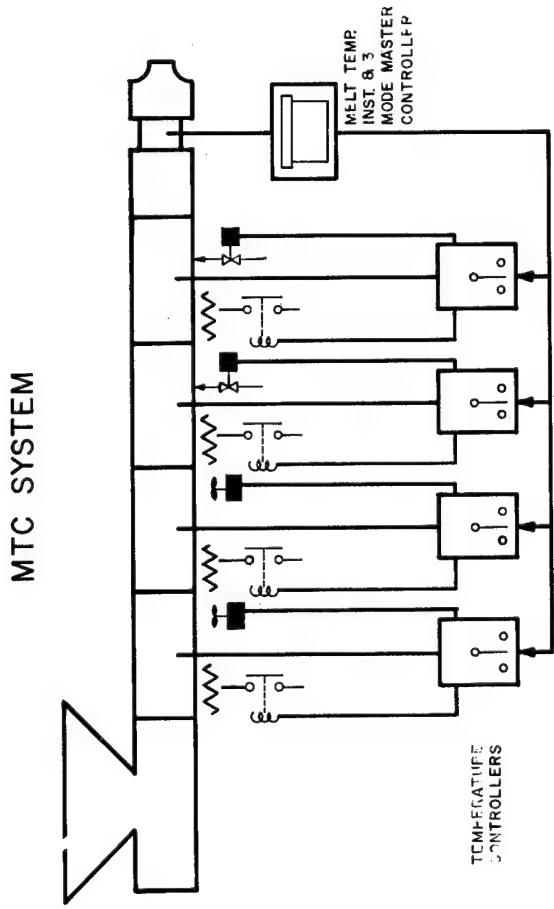
A similar designed sheet die (Figure 6) is the "flex strictor die". This die has the same flex lip feature on the adjustable lip which moves the lip gap a maximum of .030". Variation in thickness gage is accomplished with separate removable lips which are made to fit the die. These are made in increments of .030".

Example: .030" to .060" - .060" to .090", etc. The flex strictor die has the refined manifold and flow areas of the flex lip die and in addition the restrictor bar. Plastics resident time is short. A typical example: A 106" long die, making .250" thickness sheet @ 3000#/hr. of high molecular weight plastics; the resident time is approximately 8 seconds. The restrictor bar is the primary adjustment for extrudate gage and additional fine touch to correct gage is handled with the lip adjustment bolts - spaced on 1" centers. Comparing the flex strictor die with the commonly used sheet die, the advantages of the flex strictor are:

1. Uniform flow of plastics with no stagnate areas for degradation.
2. Body design which permits closer discharge from lips to the roll nip.
3. Less parts makes for easier and faster cleaning.
4. 45° angle of adjustment bolts are more convenient for operator.
5. No heat transfer loss due to bolted on lips.

#### CONCLUSION

1Dies of flex lip construction are currently in use in widths up to 162" and in gage thickness up to .250" and doing an excellent job.



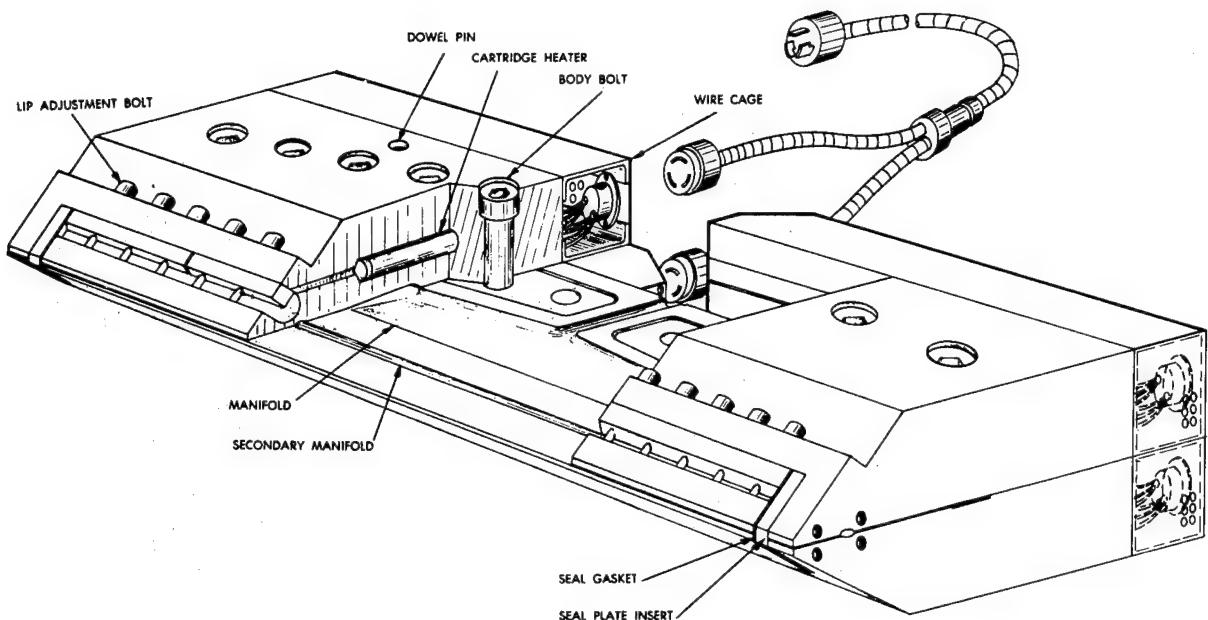


FIGURE 5: Flex Lip Film Die

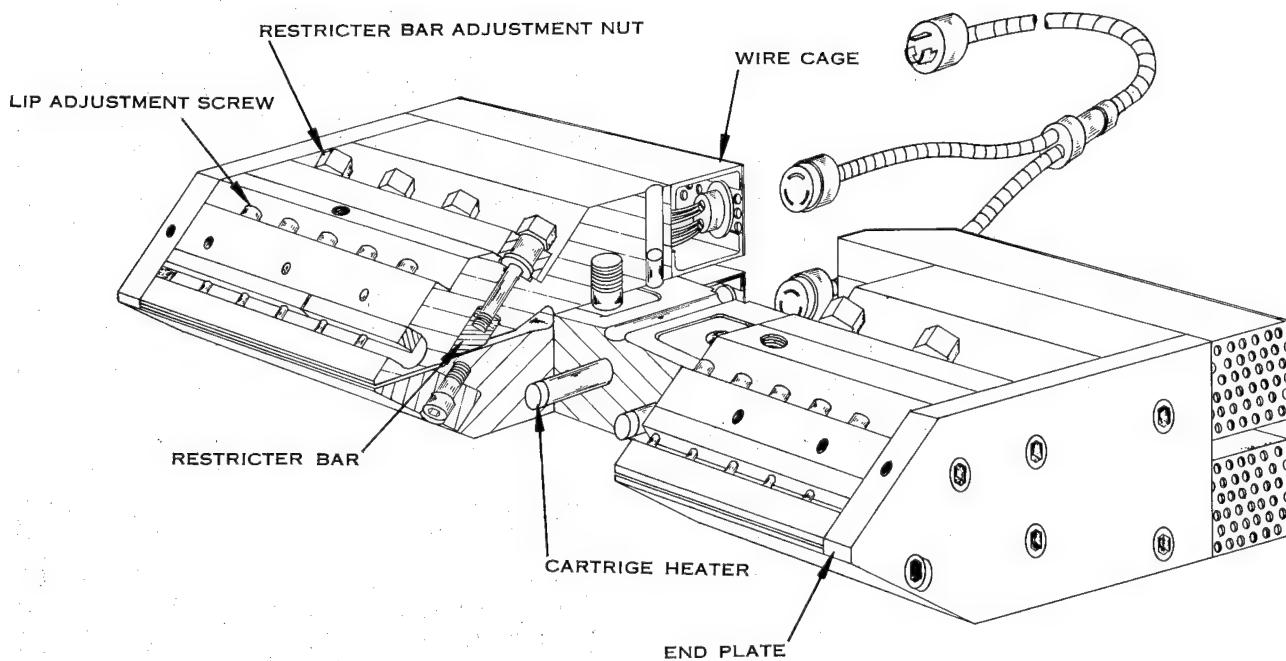


FIGURE 6: Flex-Stricter Film & Sheet Die

OJ/

EXTRUDING AND THERMOFORMING EXTRA HIGH MOLECULAR  
WEIGHT HIGH DENSITY POLYETHYLENE

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and

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#### INTRODUCTION

In order to identify the high density polyethylene material selected as the subject material for this paper, it is necessary to characterize it by molecular weight. Weight average, viscosity average, and number average molecular weights are used to identify various families of polyethylene; however, weight average molecular weights are the most frequently quoted values. For this reason, the same method will be used in this paper.

The experimental and commercial high density polyethylenes can be conveniently divided into four groups by using weight average molecular weight. The first two groups, low molecular weight (LMW) and high molecular weight (HMW) materials, have weight average molecular weights in the range of 50,000 to 250,000. These are the materials which can be characterized by using melt index (ASTM D1238-65%), which is related to molecular weight and constitutes the largest volume of commercial high density polyethylenes sold today. The third group, the subject of this presentation, has weight average molecular weights in the range of 250,000 to 1.5 million. These materials are characterized as extra high molecular weight (EHMW) materials. The fourth group having a weight average molecular weight of 1.5 million and above is termed ultra high molecular weight (UHMW) materials.

The flow properties of EHMW and UHMW high density polyethylene are determined by using condition F of ASTM D1238-65T ( $190^{\circ}\text{C}.$ , 21,600 grams load). This property is often referred to as high load melt index (HLMI). Although the melt index (ASTM D1238-65T) would be zero for the EHMW materials, HLMI values of the resins discussed herein fall between 1.5 and 6 grams per 10 minutes. Physical properties of several of these resins are given in Table I.

Processability, toughness and environmental stress cracking resistance depend upon molecular weight. Increases in weight average molecular weight usually lower

processability, but increase toughness and environmental stress cracking resistance. This criterion follows a general rule which many people in the plastics industry understand. That is, when one basic resin parameter is changed, certain advantages and disadvantages are observed as a result of this change. In the following discussion, information is presented to describe some of these advantages and disadvantages as they relate to EHMW high density polyethylene.

## DISCUSSION

### A. Polymer Properties

Within the family of EHMW HDPE, both copolymer and homopolymer resins are being produced. As seen in Table I, a range of melt flow is possible (1.5-6.0); flexural modulus of the homopolymers is higher by 60,000 psi, and the copolymers exhibit a pronounced increase in environmental stress cracking resistance. The 1500 hrs. and 150 hrs. for EHMW copolymers and homopolymers can be compared to 250 and 60 hrs. for the normal HMW copolymers and homopolymers used in blow molding or wire and cable applications.

### B. Sheet Extrusion

The sheet line at our Sales Service Laboratory has been used to extrude sheet from 1.5, 3.5 and 6.0 HLMI EHMW polyethylenes. This equipment consists of a standard 3-1/2" extruder, single stage-single screw, 20:1 L/D ratio, 75 HP drive, 40" wide slot die, and five roll polish stand. A description of the screw is included in Table II.

The purpose of our initial study was to determine if an acceptable quality sheet could be produced on a conventional single screw machine. The results of our first effort are listed in Table III. This data indicated that stock temperatures will be in the range of 80-90°F higher than experienced with HMW HDPE, cylinder and head pressures increased by about 20-40 per cent, and reduction in output can be anticipated. The sheet surface appearance of natural and pigmented sheet was acceptable.

Further studies have produced more promising results in that output rates have been increased. This process is attributed to a more desirable screw design for EHMW HDPE. Table IV includes equipment and screw description as well as the extrusion results reflecting considerable increase in output rates. Our first study yielded extrusion efficiencies of about 1 lb/hr/hp and this more recent study gave 3 lb/hr/hp. If the proper amount of heat and shear is added with the proper screw design, it is possible to extrude EHMW resins into a good quality sheet.

### C. Screw Design

To optimize the extrusion of any resin, we know we should use a screw designed just for that resin. However, the processor will generally use the screws he has available when processing a new resin, until a suitable screw design has been developed for this resin. EHMW polyethylenes can be extruded using the

screws now in use for high density polyethylene; however, the high compression ratio, the short feed section and the slightly shallow metering section will cause excessive working of the melt with resultant high melt temperature generation, high horsepower consumption and low extrusion rate.

Our studies have shown that properly designed single stage and two stage screws (non-vented) can process adequately the EHMW resins. Though we have extruded these resins on 20:1 L/D extruders, we believe the 24:1 L/D barrel length to be more desirable simply because more barrel heat can be applied to the resin before the resin is subjected to shear in the transition section with resultant uncontrolled melt temperatures. With the longer barrel, we like to see a longer feed section in the screw in the range of 8 to 10 flights so that we can take advantage of all the barrel heat available. A tapered transition section of about 8 or 9 flights appears to be adequate and a deep metering section 5 to 7 turns in length would be desirable. The longer length of metering section is desirable at the higher screw speeds (above 100 RPM) for adequate melt homogenization at these higher extrusion rates.

At this stage of our screw development program, the most acceptable 2-1/2"-24:1 L/D single stage screw evaluated had the following configuration: Feed - .500" deep x 10 flights; transition - 9 flights and meter - .165" deep x 5 flights. Previously, we had described the configuration of a 3-1/2"-24:1 L/D two stage screw that performed acceptably with these resins. Here again we see that the lower compression ratio and deeper metering sections are beneficial.

In view of the increasing interest in twin screw extruders in this country, we plan to evaluate the processability of these resins on this type of equipment as it becomes available. Some claims have been made about the suitability of the twin screw extruder for the extrusion of EHMW polyethylene; however, we cannot verify these claims at this time.

#### D. Thermoforming

Historically, the thermoforming industry has a need for high density polyethylene materials exhibiting a minimum amount of sag during the heating of the sheet. There are two basic problems associated with excessive sag. During the heating stage, the sheet comes in contact with the lower heater and can produce a fire in the thermoforming machine. Secondly, the sheet folds and produces a web in shallow draw items, if it has excessive sag.

Obviously, the basic reason for the minimum sag characteristics of EHMW materials is the high melt strength they possess. The strength of the plastics while it is in the molten state is important in any molding process, especially blow molding and thermoforming. Although there appears to be no industry-wide method of determining melt strength, the degree of sag is used extensively to qualify thermoforming resins. The high melt

strength and minimum sag characteristics of the EHMW HDPE materials identify them as a qualified family of resins available to the thermoforming industry. From the processor's viewpoint, this is the advantage associated with these materials.

Tables V and VI list thermoforming data which compare the EHMW copolymers and homopolymers with HMW copolymers and homopolymers. Table V was prepared as a result of our experience with a shallow draw part and Table VI with a deep draw part. The values listed under "sheet sag", support the above discussion concerning this characteristic of the EHMW materials. The inches of sag associated with the EHMW homopolymer is as low as 1-1/2" for a clamp opening of 25" x 48", compared to 8" for HMW copolymer. These values demonstrate the importance of considering the EHMW materials when thermoforming shallow draw parts with draw ratios of 0.7:1 and less. Using the same reasoning, deep draw parts will be more difficult to thermoform satisfactorily. Excessive thinning in the bottom and even tearing will sometimes occur.

#### E. Thermoformed Part Performance

Parts made from EHMW polyethylene are characterized by outstanding stress cracking resistance, good impact strength, and toughness. They are particularly suited for large thermoformed parts, such as tote boxes, pallets, large dunnage and shipping containers.

Realizing that Izod impact values fail to reflect part performance, it is significant to examine part drop impact. Since most thermoforming applications do not lend themselves to filling with water and dropping from a given height, it was necessary for us to use a blow molded item. The test consisted of filling a 20 gallon container with water and dropping it from various heights to establish an F<sub>50</sub> value. The EHMW high density polyethylene containers had an F<sub>50</sub> value of 30 feet and the HMW containers had an F<sub>50</sub> value of 11 feet. Both tests were performed with containers having a minimum wall thickness of approximately 0.068 inches. Many of these tests have been performed and in all cases the data have indicated the excellent impact resistance of EHMW materials.

#### CONCLUSIONS

*The discussed in this paper this company's*  
This work is an extension of our extrusion effort to learn more about the processing requirements for a new family of high density polyethylenes. The mere knowledge that a family of EHMW HDPE can be produced on a commercial scale, or the understanding of the techniques employed to process these materials, is not adequate justification for their production and marketing. It is recognized that the number of different resins which can be produced is nearly limitless. However, there must be a demand for a resin with a particular set of properties before it is produced.

Work completed to date indicates that the desirable properties of EHMW high density polyethylenes can be fully realized by processing these resins on conventional single screw extrusion equipment. It is reasonable to expect some reduction in output rates; however, output rates can be appreciably increased by optimizing the screw design.

It is important to select thermoforming applications which demand the good physical properties and minimum sag characteristics of the EHMW polymers. Although not included in this paper, these materials have been processed into pipe, blow molded, and coated on wire. Thus, it is not surprising that they have been extruded into sheet and successfully thermoformed into high performance parts.

Historically, we have tried to meet the demand of the plastics industry in creating new resins. The new EHMW resins are the results of research know-how, assisting us to meet the challenge of the future.

TABLE I

PHYSICAL PROPERTIES OF EXTRA HIGH MOLECULAR WEIGHT RESINS

		<u>Copolymers</u>			<u>Homopolymer</u>
Density, gms/cc	D1505-65%	.943	.941	.941	.955
Melt flow, cond. F*, gms/10 min.	D1238-65%	6.0	3.0	1.5	3.5
Environmental stress cracking resistance, hr., F <sub>50</sub>	D1693-60%	> 1500	> 1500	> 1500	150
Tensile yield strength, psi 2"/min.	D638-65T, Die C of D412-66	3000	3000	3000	3000
Ultimate elongation T 2"/min.	D638-64T, Die C of D412-66	600	600	600	600
Impact strength, ft.lbs./in. notch	D256-56	7	7	7	16
Vicat softening temp, °F.	D1525-65T	258	258	258	260
Brittleness temp., °F.	D746-64T	<180	<180	<180	<180
Flexural modulus, psi	D790-66	140,000	140,000	140,000	200,000
Hardness, shore D	D1706-61	64	64	64	68

\*Sometimes referred to as High Load Melt Index (HLMI)

TABLE II

CONVENTIONAL SHEET LINE

Extruder	.....	3-1/2" dia. Royle, 20:1 L/D, 75 HP
Screw	.....	16-1/2 turns feed - 0.430" channel depth 5 turns metering - 0.116" channel depth 1/2 turns transition
Die	.....	40" wide slot die with choke bar
Sheet Train	.....	Five roll 12" dia. polish stand, conveyor and haul-off unit

TABLE III  
 INITIAL COMPARISON OF SHEET EXTRUSION CONDITIONS  
 FOR EHMW AND HMW POLYETHYLENES

	<u>EHMW Copolymer</u>	<u>EHMW Homopolymer</u>	<u>HMW Homopolymer</u>	
Density, gms/cc	.943	.955	.960	
Melt flow, cond. F*, gms/10 min.	6.0	3.5	0.1**	
Die opening (inches)	0.250	0.250	0.250	
Sheet gauge (inches)	0.125	0.150	0.125	
Screw RPM	20	20	30	
Cylinder Temp. ( <sup>o</sup> F)	Zone 1 Zone 2 Zone 3 Zone 4	450 460 470 480	440 460 505 510	370 380 390 400
Stock temp. ( <sup>o</sup> F)		500	545	420
Die temp. ( <sup>o</sup> F)	Zone 1 Zone 2 Middle Zone Zone 4 Zone 5	480 480 480 480 480	500 500 500 500 500	400 400 400 400 400
Roll temp. ( <sup>o</sup> F)	Top Middle Bottom No. 4 No. 5	225 245 225 210 150	210 240 230 210 100	215 220 225 170 155
Head pressure (psig)		2750	3500	2400
Cylinder pressure (psig)	Zone A Zone B Zone C Zone D Zone E	2550 3825 5200 6400 4125	2100 3650 5200 6800 4700	1400 2700 4100 5300 3475
Line speed (in/min)		9	6-1/4	11-1/2
Output (lb/hr)		80	75	115
Amps		93	97	92

\*Sometimes referred to as High Load Melt Index (HLMI)

\*\*Melt Index, Cond. E, gms/10 min.

TABLE IV

TYPICAL EXTRUSION CONDITIONS FOR EHMW POLYETHYLENE

Extruder: 3-1/2 dia., 24:1 L/D, 150 HP  
Screw: (Two stage)

Back stage: 8.3 turns feed, 0.500" channel depth  
2 turns tapering transition  
4 turns metering, 0.187" channel depth

Front stage: 1.7 turns feed, 0.500" channel depth  
4 turns tapering transition  
4 turns metering, 0.250 channel depth

Die: 52" wide slot die with choke bar

Sheet train: Five roll 12" dia. polish roll stand, conveyor and haul-off unit.

EHMW Homopolymer

Density, gms/cc	0.955
Melt flow, cond. F.*, gms/10 min.	3.5
Die opening (inches)	0.200
Sheet gauge (inches)	0.125
Screw RPM	60
Barrel temperature, °F	450 to 500
Stock temperature, °F	530
Head pressure, psi	3200
Die temperature, °F	525
Output, lbs/hr	247
lbs/hr/hp	3

\*Sometimes referred to as High Load Melt Index (HLMI)

TABLE V

A COMPARISON OF THE THERMOFORMING CHARACTERISTICS OF  
(EHMW) AND (HMW) IN A SHALLOW DRAW ITEM

Resin	<u>EHMW Copolymer</u>	<u>HMW Copolymer</u>	<u>EHMW Homopolymer</u>	<u>HMW Homopolymer</u>
Sheet thickness (inches)	0.125	0.125	0.125	0.125
Clamp opening (inches)	25" x 48"	25" x 48"	25" x 48"	25" x 48"
Blanksize (inches)	27" x 50"	27" x 50"	27" x 50"	27" x 50"
Number of heaters	2	2	2	2
Type of mold	- - - - Female - - - - Aluminum Casting			
Item	Sled	Sled	Sled	Sled
Draw ratio	0.2:1	0.2:1	0.2:1	0.2:1
Mold temperature (°F)	180	180	180	170
Heater temperature (°F)	1,200	1,200	1,200	1,200
Heating time (top heater, sec.)	55	68	55	74
(bottom heater, sec.)	34	32	34	32
Cooling time (sec.)	180	180	180	180
Sheet sag (inches)	3-1/2	8	1-1/2	4
Sheet appearance	Dull surface	Good	Dull surface	Good
Part appearance	dull and slightly grainy surface	Good	Dull and slightly grainy surface	Good

TABLE VI

A COMPARISON OF THE THERMOFORMING CHARACTERISTICS OF  
(EHMW) AND (HMW) IN A DEEP DRAW ITEM

Resin	EHMW Copolymer	HMW Copolymer	EHMW Homopolymer	HMW Homopolymer
Sheet thickness (inches)	0.125	0.125	0.125	0.125
Clamp opening (inches)	15" dia.	15" dia.	15" dia.	15" dia.
Blank size (inches)	18" x 18"	18" x 18"	18" x 18"	18" x 18"
Number of heaters	2	2	2	2
Type of mold	----- Male ----- Aluminum Casting -----			
Item	Wastebasket	Wastebasket	Wastebasket	Wastebasket
Draw ratio	1.5:1	1.5:1	1.5:1	1.5:1
Mold temperature ( $^{\circ}$ F)	180	180	180	180
Heater temperature ( $^{\circ}$ F)	1,200	1,200	1,200	1,200
Heating time (top heater, sec) (bottom heater, sec)	38 38	34 34	40 40	40 40
Cooling time (sec)	180	180	180	180
Sheet sag (inches)	1/2	2	0	3/4
Sheet appearance	Good	Good	Dull surface	Good
Part appearance	Thin bottom	Good	No part Draw too deep	Good

## HIGH-SPEED EXTENSION OF POLYSTYRENE SHEET

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In recent years, polystyrene sheet extrusion technology has advanced rapidly through the efforts of the raw material supplier, equipment supplier, and the sheet producer.

The raw material supplier has been required to develop materials which can be processed at high speed and at the same time provide properties which meet the end product requirements. These requirements vary widely from one end product to another as indicated in the following.

Thermoformed containers such as drinking cups, cottage cheese containers, lids, etc., require a polystyrene which can be processed with a low orientation level, satin finish, high impact strength, and high elongation. The polystyrene must be capable of 500°F. extrusion temperature and re-extrusion at similar conditions many times without color change or significant loss of the above properties due to thermal instability.

Refrigerator and appliance thermoformed sheet requires a material which can provide high gloss without the use of heat glazing units (the use of which tends to reduce physical properties of the polymer) and will retain high gloss after vacuum forming. This is also an application where thermal stability is required for high extrusion temperature and re-extrusion at similar condition. However, the problem is generally not as severe in this application as it is in thermoformed container processing. High impact, elongation, tensile strength, and chemical resistance are also required in this application.

A further requirement of the polymer which is common to all high speed extrusion applications is that "screw loading" not occur. This is an inter-related condition between raw material selection and machine and screw design, as well as method of operation. Quite often, the latter two are quite proper but the material selection is not. While no one makes a fool-proof material, there is a distinct difference between those which are capable of high quality, high speed extrusion and those which are not.

The following is an indication of sheet extrusion performance in the field today for various size extrusion lines.

<u>24:1 L/D Ratio (Single stage)</u>		<u>24:1 L/D Ratio (2-Stage vented)</u>	
<u>Screw Diameter</u>	<u>Lbs./Hr.</u>	<u>Screw Diameter</u>	<u>Lbs./Hr.</u>
2-1/2"	175-200	2-1/2"	250-300
3-1/2"	375-425	3-1/2"	450-550

4-1/2"	600-700	4-1/2"	1000-1200
6"	1100-1200	6"	1600-1800

In addition to the proper selection of material, careful consideration must be given to many design factors of the extrusion equipment to enable successful high speed extrusion.

Air which contains moisture is taken into the extruder along with the polymer. All air and moisture must be prevented from reaching the die if quality sheet is to be produced.

Dehumidifying hopper-dryers can remove the moisture from the air but not the air itself. Vacuum hoppers can remove much of the air if this unit is properly maintained. The vacuum hopper relies on a vacuum seal on the screw at the rear of the feed section of the extruder. With high extrusion rates and increased screw speeds, it has been increasingly difficult to design a seal of this type to last a reasonable length of time. This problem can be appreciated when one realizes that a 6" extruder running 130 rpm has a screw surface speed of 200 feet per minute. This presents a substantial wear problem in addition to the fact that the screw runs at elevated temperature and is dry at this point.

The most suitable solution to the air and moisture problem is the vented extruder, which takes in nearly as much air and moisture as a single-stage extruder but removes all volatiles through the vent.

Screw design is certainly the most important single factor regarding extrusion equipment design, and the performance of the entire line will be governed by the suitability of the screw (see Figure 1). Screw design and the requirements of each section can be broken down into sections as in the following:

A. Feed Zone

The primary function of the feed zone is to pick up material and convey it forward to the transition zone. Properly designed polystyrene screws will have a feed zone length of approximately six flights. This provides enough length and time for the material to preheat and begin the drag flow process. The feed zone should be designed with approximately four times the metering pump volume to insure that the metering pump is kept full of polymer.

B. Transition Zone

The transition from solid to melt should be fairly rapid. Four to five flights usually are required in this zone. This will vary from single-stage to two-stage screws.

Approximately 80 per cent to 90 per cent of the total heat of the polymer mass is developed in this zone due to shear and compression.

C. Metering Zone

The metering zone (on 2-stage vented screws, the first metering zone) determines the output of an extruder. The shallow flight

depth, as well as the length of this section, completes the homogenizing process. Since the resin is a melt in this zone, regular pump design calculations can be used to determine the output capacity of the screw. This is referred to as the drag flow equation which is obtained in lbs/hr by the following:

$$2.3D^2Nhp$$

where D is the inside cylinder diameter inches

N is screw speed rpm

h is channel depth of metering pump in inches

p is specific gravity of polystyrene at 80°F

Example:

A 4-1/2" extruder having a screw metering pump depth of .150" producing polystyrene at 150 rpm

$$2.3 \times 4.5 \times 4.5 \times .150 \times 1.04 = 1092 \text{ lbs/hr}$$

This formula applies directly to two-stage screws running vented where the metering zone is not opposed by back pressure. Single-stage (non-vented) screw output can be calculated by use of the same formula. However, the output rate of a similar screw design will be somewhat lower due to the back pressure component. Considering the screw functions we have discussed to this point, the following comments are in order.

1. Both 2-stage (vented) and single-stage (non-vented) screws must deliver polymer from the metering zone in a condition suitable to go through a die and to make product.
2. A single-stage screw requires the use of hopper-dryers to eliminate moisture from being delivered through the die. The single-stage screw must be run at a speed limited to air removal back through the hopper.
3. The 2-stage screw does not require a hopper-dryer. Any trapped moisture and air which passes through the metering zone is removed at the vent zone.

#### D. Vent Zone or Decompression Section

In this portion of the screw, the polymer pressure is lowered to atmospheric pressure, or below atmospheric pressure if vacuum is applied. This allows complete removal of gases caused by air, moisture, etc.

This section of the screw normally consists of four to five flights with a volume increase of four to five times over that of the rear metering pump.

Vented extruders have a maximum operating back pressure which is generally in the range of 2,500 psi to 4,000 psi. This maximum pressure is determined by screw design, resin viscosity, screw speed, and operating zone temperatures of the cylinder. When vented extruders are operated above this maximum pressure capability, polymer will be forced out the vent.

#### E. Front Pump

This section is also referred to as second pump, or pumping zone. The function of this pump is to accept molten polymer from the vent zone and generate enough pressure to force it through the screen pack and die system. The volume or depth ratio of this pump is normally two times that of the rear metering pump. The front pump normally consists of four to five flights.

The operating principle of the conventional two-stage screw is as follows: By design, the two-stage screw basically consists of two screws on one shaft; the first screw operates against no back pressure, while the second screw does. Screws of this type are not positive displacement pumps and, therefore, their output capacity is sensitive to back pressure.

If we assume a 4-1/2" screw having a first stage metering pump of .150" depth operating at 150 rpm will provide 1092 lbs/hr, the front pump having twice the volume will be .300" deep and will have a capacity of delivering 2184 lbs/hr with no back pressure (open head). When we insert a screen pack and close the head, back pressure in the order of 1500 to 2000 psi will be generated. This, in turn, lowers the front pump capacity from 2,184 lbs/hr to a lower figure, closer to the rear pump delivery of 1092 lbs/hr. On most two-stage screws, we are still not in balance (surge free). To obtain this balance, a variable back pressure valve is used to further reduce the capacity of the front pump to a point near 1092 lbs/hr where the machine will stabilize.

The use of an adjustable pressure valve provides a means of reducing the back pressure as the screen pack fills up, thereby maintaining a constant back pressure until the valve is in a wide open setting and the back pressure generated by the screen exceeds the pumping capacity of the screw. At this point the screens will have to be changed and the valve brought back to a start position.

Operating in this manner is most desirable since all of the polymer passing through is processed under identical conditions, including back pressure.

Temperature control of both heating and cooling must be automatic. Both heating and cooling capacity must be sufficient to do the job required of it; however, this capacity should not be excessive. Over-capacity of either heating or cooling causes cyclic temperature control which will cause feed variation and, in turn, sheet thickness variation. Thermocouple tip location should be equal distance between the cylinder outside diameter (heating and cooling source) and the cylinder inside diameter (frictional heat source) to provide smooth response and avoid over-control.

Screen Changer - The use of a properly designed screen changer substantially increases the efficiency of sheet extrusion equipment by means of a reduction of down time for screen change. When extruding regrind, a certain amount of contamination is encountered, the amount depending upon the care taken in grinding the

scrap as well as general handling. The higher the rate of regrind to virgin, the higher the amount of contamination. In production of thermoformed containers, a rate of 50 per cent regrind to 50 per cent virgin is commonly run; while rates as high as 70/30, respectively, at times are required. With such mixtures, screen change intervals of six hours are common. With a screen changer, approximately five to ten minutes production time will be lost with the screen change being done between rolls.

This very rapidly repays the purchase price of the screen changer when one considers that one to two hours of production time can well be lost at each screen change if the extruder is to be stopped and the head opened.

The Sheet Die - The die is a very important part of the entire operation. It must be kept clean both inside and out. The screen pack helps to protect the die, as well as deliver a homogeneous melt. The heaters must be checked periodically to insure precise heat control. The die lips must be kept free of nicks and burrs because blemishes affect the appearance and physical quality of the sheet. The die lip opening should be determined by the sheet thickness prior to starting the extruder. The die lip opening should never be set more than 10 per cent over the sheet thickness to be produced. An example: 10 mil sheet to be produced should have a die lip opening of 0.011". This provides a 10 per cent maximum drawdown for 0.010" sheet.

An important consideration for thin sheet production is die lip design. In setting the die lip at .011" opening, high pressure is generated at the lip. High pressure at this point will cause the die to spring open in operation. In addition, this pressure will add unnecessary high pressure to the extruder screw. To correct this, die lips of short land length are used. A land length of 0.50" is commonly used which for .010" thick sheet provides a land length over opening ratio of approximately 50:1.

This lip is suitable for sheet thicknesses up to .040". The distribution of material should be handled by use of the restrictor bar (choker bar). This method of adjustment offers even distribution of pressure and reduced die lip deflection. This will also minimize variation of orientation level across the sheet width.

The ideal way to operate a sheet die with regard to the highest quality sheet is to set the die lip opening as near final sheet thickness as possible (minimum stretching). Set the lip opening at a uniform gap over entire width. This will determine the sheet thickness leaving the die lip. From this point on, only flow pressure adjustments are required which is accomplished with the restrictor bar.

One can easily determine whether or not a die in operation has been properly adjusted. To do this a marking pen is used to draw a line across the sheet at the die face. When this line travels to the rubber draw rolls it should remain in a relatively straight line, indicating a uniform stretch out of the die. A snaking line indicates variable stretch and variable orientation.

Temperature of the die should be within 4 per cent of the temperature of the melt (stock temperature). The temperature of the outer edges of the die may be slightly higher to provide a more even flow distribution of material. Temperature controllers should be set on a minimum cycle because the temperature affects the pressure at the die exit.

Polishing Rolls - Xaloy, hardened chrome-plated or stainless steel hardened rolls are preferred. While their diameter will depend upon the amount of polymer

to be cooled and the speed at which the sheet travels, the following is an indication of the roll diameters commonly used with various extruders.

<u>Extruder Diameter</u>	<u>Polish Roll Diameter</u>
2-1/2"	8"
3-1/2"	8"
4-1/2"	18"
6"	18"

The contact time must be sufficient to remove enough heat from the sheet to lower the temperature below its heat distortion point.

The chrome rolls should be parallel to and level with the sheet and should pull straight from the die lips. The rolls should be kept clean, and care should be taken never to dent or scar the surface. Any imperfection in the rolls shows up as an imperfection in the sheet. Each roll should be equipped with a separate temperature system. The temperature of the center roll should be approximately 10°F below the stick point of the polymer.

Excessive temperature on the top roll will "polish" the sheet. Excessive bottom roll temperature may allow the rubber pull rolls to stretch the sheet causing severe orientation.

Chatter marks may be avoided with correct roll temperatures. Top and bottom roll pressures should be at a minimum. The clearance between the rolls should be slightly under the gauge of the sheet. The physical properties (orientation, impact) are better on a "cast" sheet than sheet extruded under high roll pressures. Crazing or cracking are results of high roll pressures.

Rubber Pull Rolls - The rubber rolls should provide a constant tension on the sheet. Rubber pull roll tension should be held at a minimum level where proper tracking of the sheet through the system can be maintained. Tension of the draw roll should never be used for sheet thickness or width change. This is a major cause of machine direction orientation. The speed control of the polish and rubber rolls should preferably be from a common control potentiometer with a secondary speed trim adjustment for rubber roll speed.

## SHEET QUALITY REQUIREMENTS

### A. Dimension

Successful thermoforming of containers is to a very large degree dependent upon sheet thickness uniformity. It is the forming phase of container production which dictates the amount of thickness variation to be accepted. Material cost is also influenced by non-uniformity. Unfortunately, the permissible variation of thickness decreases in percentage as the sheet thickness increases. Lid stock material at .011" thickness is run at a tolerance of plus or minus .0005" while 32 oz. deep draw container material of .080" thickness must be held to a tolerance of plus or minus .0015". The lid stock tolerance is approximately 10 per cent of the mean thickness while the 32 oz. stock tolerance is 3-3/4 per cent.

It is far more difficult to run the heavy sheet at high speed than the thin sheet at high speed, in view of the above.

B. Orientation

The commercial classification of orientation for extruded sheet in various thicknesses is shown in Figure 2. The most noticeable result of high orientation is brittleness which will appear in one direction of the container much more so than a direction 90° away from this point. High orientation is also frequently the cause for much lip rolling trouble due to differential shrinkage upon heating.

C. Gloss

High surface gloss on the sheet is not desirable for thermo-forming of containers at high speed. High gloss sheet reflects heat in the heating station of the former and retards the heating and forming cycle. A dull surface is not desirable in the finished container from the consumer point of view. Materials have been specifically developed to provide a satin-like finish which produces an appealing product and yet does not create problems encountered with high gloss.

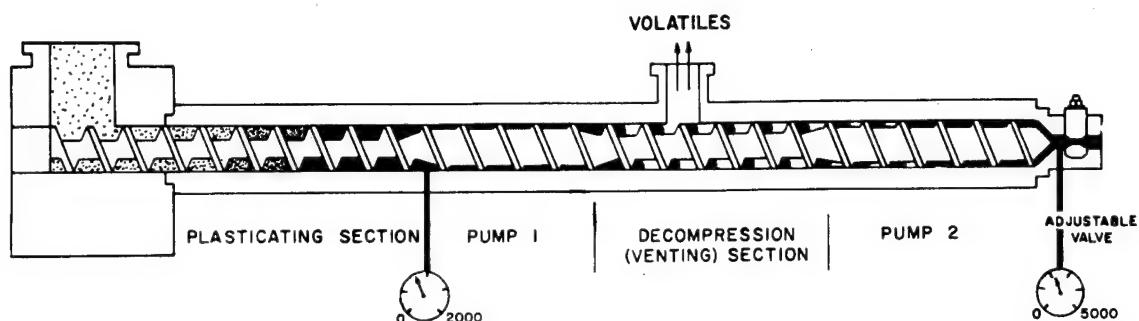
Equally important to high-speed sheet extrusion and polymers designed for highspeed processing, some polystyrene is also supplied in bead form and is being extruded on equipment described in this article. Processing rates are equal to, and in many cases exceed, those of conventional pellet extrusion.

The primary advantages of the use of beads rather than pellets are substantial cost savings, additional heat stability, and improved mixing during extrusion.

L/D RATIO 20:1



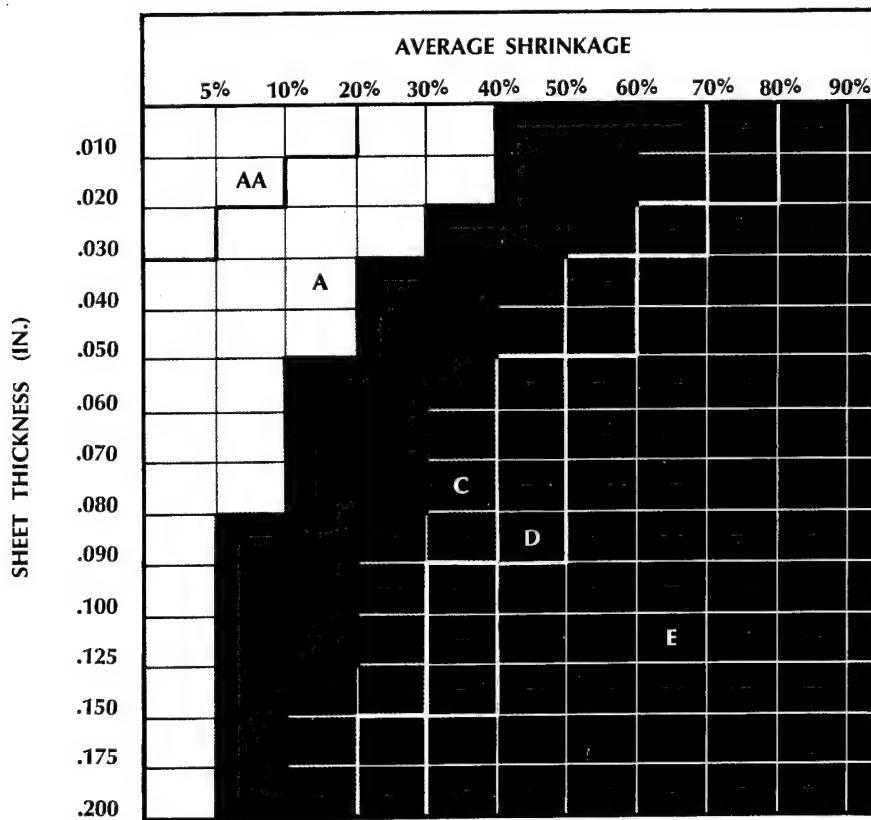
A. Single stage, constant pitch, increasing root diameter screw



B. Two stage, devolatilizing screw

FIGURE 1

ORIENTATION RATING FOR HIGH HEAT,  
HIGH IMPACT POLYSTYRENE SHEET



IF VARIANCE ACROSS SHEET EXCEEDS 5% DOWNGRADE 1 CLASS

IF VARIANCE ACROSS SHEET EXCEEDS 10% DOWNGRADE 2 CLASSES

FIGURE 2

## COLD FORMING OF ABS PLASTICS

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#### INTRODUCTION

< During the last few years, considerable attention has been giving to cold forming of plastics as a method of converting thermoplastics materials into finished parts starting from semi-products elaborated in form of sheets, rods, billets, etc.

< The work done to date has been almost exclusively directed in adapting metal working techniques. These techniques are particularly attractive for plastics converting, because of the availability and relatively low cost of basic equipment, the high production rates, and other advantages directly related to the materials used for a particular application.

< This paper describes the methods of cold forming that have been employed, using various thermoplastic materials; but, since most of the work done at Marbon has concerned the deep drawing of ABS sheet, emphasis is placed on this particular process. >

#### COLD FORMING METHODS

The methods used to cold form metals which have also been tested on thermoplastics materials, are as follows.

##### 1. Stamping

Forming a shallow part (depth generally not greater than 1/4") through "stretch flow" of material confined between two matching steel members or one steel member and a hard rubber member as schematically shown in Figure 1.

Example: Signs, license plates, lids, etc.

##### 2. Coining

Forming a very shallow part, generally to reproduce engraved decorations through "compression flow" of material inside a two-steel-parts die, one being flat and the other bearing the engraving to be reproduced on the part.

Examples: Coins, medals, buttons, etc., as schematically represented in Figure 2.

3. Cold Heading

Forming parts through large "compression flow" of material inside a steel die. The principle is similar to coining, although displacement of material is generally of greater importance.

Example: Screws, bolts, knobs, as schematically shown in Figure 3.

4. Fluid Forming

Forming parts through a combined "compression and stretch flow" of material confined between a steel punch and a rubber diaphragm to which a high hydrostatic pressure is applied (10,000 to 15,000 psi). This method is schematically illustrated in Figure 4, and permits production in one or two steps of shapes, such as cones, hemispheres or intricate parts, which would require a great number of operations when made by other cold forming methods. Tooling costs are generally low, but the speed of operation is relatively slow, basic equipment is rather expensive, and the size limitation of the blank diameter is 32 inches.

5. Explosive Forming

Has been recently investigated for light metals (aluminum) and has given good results for large parts. It consists of shaping the material at a very high deformation rate obtained by the explosion of a charge of TNT located inside a noncompressible media, as illustrated schematically in Figure 5. Cast iron, concrete and even ice molds have been used for that purpose.

6. Spinning

Shaping a part through "compression flow" of material obtained in applying high pressure localized on a small area (spinning tool or rollers) and moving the pressure application point on the surface of the material as schematically shown in Figure 6.

7. Deep Drawing

Is, at the present time, widely used for cold forming metals and consists of converting a flat piece of material into a seamless hollow shape through a balance of "compression and stretch flows" of the material confined between two members of a tool, so that no substantial change in thickness between the original sheet blank and the part exists.

## DEEP DRAWING OF ABS PLASTICS MATERIALS

A. Materials and Their Properties

The general definition of deep drawing given above indicates that the materials to be formed must have the physical properties which will permit plastics flow at high speed and room temperature

without necking, buckling, spring-back or fracture in order to obtain a part having the desired shape and dimensions.

Marbon Chemical Division of Borg-Warner Corp. has developed, to date, two ABS compounds which offer good drawing characteristics. They are:

Cycopac 155, particularly designed for food applications.

Cycolac MS formulated for industrial applications.<sup>1</sup>

Since we are borrowing heavily from metal forming technology to deep draw ABS materials, it is of interest to compare the mechanical properties of ABS and metals (see Figure 7).

This table shows a large difference in properties inside the same class of metals which indicates the variety of compositions and treatments made in order to emphasize desirable properties to suit a wide range of applications.

An examination of those values leads to the conclusion that ABS materials are soft and ductile, but their drawability is not exclusively determined by physical properties.

#### B. Deep Drawing Operation

1. Drawability is a very difficult property to measure because of the many variables involved. In addition to the mechanical properties of the material, drawability depends upon the conditions of the operation such as speed, temperature, lubrication, thickness, etc., as well as tool geometry and material thickness.

Consequently, the drawability of a given material can be fairly well established through a test or a series of tests, but the results will not necessarily be applicable to all kinds of drawing operations.

A considerable amount of work is still done by the metal industry to replace guess work by application of scientific data in determination of drawability.

For plastics, the difficulties are even greater because of the high sensitivity of the high polymers to speed and temperature, and their particular stress-strain characteristics due to their viscoelastic flow under various conditions of stresses. Work is under way at Marbon to establish ABS drawability testing methods and results will be published as soon as they are available.

Drawability, for simple cylindrical forming, is generally expressed as a relationship between blank diameter, DB, and the diameter of the drawn part DB, in the following manner.

### Maximum Diameter Reduction

$$MDR = \frac{D_B - D_P}{D_B} = 1 - \frac{D_P}{D_B} = 1 - m^2 \quad (1)$$

### Limiting Drawing Ratio LDR<sup>3,4</sup>

$$LDR = \frac{D_B}{D_P} = \frac{1}{m}^5 \quad (2)$$

### Reduction Coefficient

$$m = \frac{D_P}{D_B} = 1 - MDR \quad (3)$$

In other words, drawability can be expressed as the biggest blank diameter that can be used to form a cup of a given diameter without fracturing, tearing or wrinkling.

From actual drawing tests, it has been determined that Cycopac 155 and Cycolac MS have

$$MDR = 0.45$$

$$LDR = 1.8$$

$$m = 0.55$$

for a first draw operation.

For a second draw, the values are

$$MDR = 0.25 \text{ to } 0.30$$

$$LDR = 1.35 \text{ to } 1.40$$

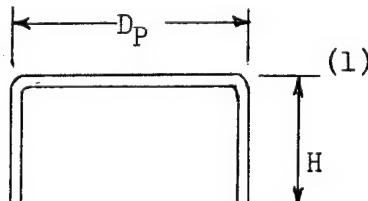
$$m = 0.70 \text{ to } 0.75$$

These three notations are used by various authors to describe drawability, some care must be taken in using them in calculations.

The preceding formulas, as well as the values found for ABS, show that sometimes several operations will be necessary to draw a part of given dimensions.

The calculations are made, assuming a perfect draw (no wrinkling, no thinning), and the surface area of the formed part being identical to the surface area of the blank.

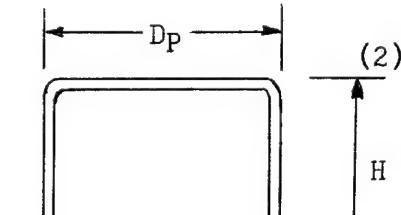
For a straight wall cup (Figure 8-A)



$$D_B = \overline{D_P}^2 + 4D_P H$$

$$\text{and } H = \frac{\overline{D_B}^2 - \overline{D_P}^2}{4D_P}$$

For a flanged cup (Figure 8-B)



$$D_B = \overline{D_F}^2 + 4D_F H$$

$$\text{and } H = \frac{\overline{D_B}^2 - \overline{D_F}^2}{4D_F}$$

These formulas only give a good approximation for relatively thin materials because they do not take into consideration the thickness of material and the various radii of the part.

Blank diameter can be calculated accurately, using conventional expressions given in handbooks dealing with deep drawing and tool design.<sup>6</sup>

From blank diameter and applying the reduction coefficient

$$m = \frac{D_p}{D_B} \quad (m = 0.55 \text{ first draw and } m = 0.75 \text{ second draw for Cycopac 155 and Cycolac MS})$$

it is possible to determine the number of draws and the various diameters obtainable on each of the successive operations to get a part having the desired dimensions.

Figure 9 shows a diagram that has been prepared for that purpose. The following examples explain how it can be used to solve different problems.

Example 1 - What is the minimum diameter a part can be drawn from Cycopac 155, from a blank 10" dia. in one operation? From oblique line 10" intersection with horizontal line ( $m=0.55$ ) draw a vertical line that crosses the horizontal part diameter scale at  $5\frac{1}{2}"$ .

Answer:  $5\frac{1}{2}"$

Example 2 - From this  $5\frac{1}{2}"$  first draw, what minimum diameter part can be obtained on the second draw ( $m=0.75$ )? Trace oblique line from  $5\frac{1}{2}$  to 0. From the intersection of this line with the  $m=0.75$  red horizontal line, draw a vertical line that intersects the part diameter scale at 4.166.

Answer: 4.166"

Example 3 - How many operations are necessary to draw a cylinder having  $3\frac{1}{2}$  diameter from a blank having 10" dia.?

1st draw  $m = 0.55$  min. part dia. 1st opr.:  $5\frac{1}{2}"$   
2nd draw  $m = 0.75$  min. part dia. 1st opr.: 4.166"  
3rd draw  $m = 0.75$  min. part dia. 1st opr.: 3.1"

Answer: 3 draws are necessary

## C. Tooling for Circular Shapes

### 1. The First Draw

The main components of a deep drawing tool are:

a. The Punch

The punch is a piece of steel of cylindrical shape around which the material is formed in such a way that the diameter of the punch will be approximately the inside diameter of the part.

b. The Die

The die is a piece of steel in shape of a ring that forces the material around the punch to form the cylindrical cup. The inside diameter of the ring being approximately the outside diameter of the part. A simple die is shown in Figure 10. Notice that the die ring is provided with a tapered section which facilitates the flow of the material toward the cylindrical section. At the end of the stroke down, the formed part is stripped down by the counterbore at the bottom of the die.

c. The Draw Ring

In the tool shown in Figure 10, the position of the blank during the drawing operation is not controlled in any way, and it has been found that, for a successful drawing, not only the position, but also the holding of the blank is very important.

Figure 11, A, B and C, are showing three different ways currently used to get the proper control over the blank. Figure 11A shows the setup used for thick materials where the draw ring is positively blocked against the surface of the die and a clearance of a few thousandths of an inch is provided into the blank space to let it flow freely during the drawing operation.

Figure 11B shows a spring loaded draw ring that applies pressure to the blank during the drawing operation in order to restrict the flow of the material.

The force of the spring should be enough to eliminate wrinkles, but not high enough to stretch and/or fracture the material. An inconvenience of this method for very deep draws is that the holding force is increasing as the draw progresses. This figure also shows the stripper-pins located on the periphery of the die to extract the part from the punch during up-stroke of the press.

Figure 11C shows three positions of a drawing tool using an inverted draw ring. Air or hydraulic pressure is applied to the pad through a series of pins accurately calibrated in length. This method has the advantage of applying a constant force to the blank during the operation. It should be pointed out that, even with a constant force applied to the draw ring, the unit pressure applied to the blank increases rapidly during the draw due to the radial flow of the material that reduces the surface area submitted to holding

pressure. Attempts have been made to program the draw ring pressure but, at high production rates, the response time of hydraulic circuits presents some problems.

d. The Blanking Ring

Instead of feeding the tool with a circular blank, a strip of material is often used and the blank is cut in the tool at the beginning of the operation, just before drawing. The cutting edges are the inside diameter of the blanking ring and the outer diameter of the die, as shown in Figure 12, illustrating a single draw cup drawing with inverted draw ring.

e. The Knock-out Pad

When an inverted draw ring is used, the formed part is stripped from the punch by the ascending movement of the draw ring during the up-stroke of the press and then, stays in the die and would remain there. A knock-out pad is located inside the die as shown in Figure 11C which is connected to the knock-out rod. During the press up-stroke, the knock-out rod hits a fixed bar adjusted in proper position and stops the knock-out pad, thus removing the part from the die. The part falls down and is removed through simple inclination of the press bed or a blast of air.

## THE SECOND DRAW

Two types of tools may be used for redrawing an ABS cup, in order to obtain a smaller diameter and deeper part.

The very same elements are used for the tooling, but are disposed in different ways and have different shapes.

A. Straight Redraw

This type of redraw is called "straight" because the restriction of diameter of the cup is done by forcing the material down in the same direction as it has been formed in the first operation.

A typical tool for straight redraw is shown in Figures 13A, B and C. Notice that the cup is placed over a shaped draw ring which automatically centers it in the tool for the drawing operation. Drawing and ejection are done in a very similar fashion, as shown in Figure 11C, first draw.

B. Inverted Redraw

This operation is called "inverted redraw" because of the fact that during redrawing, the cup walls are turned over so that the inner face of the first draw cup makes the outer face of the finished cup. A tool for inverted redraw is shown in Figures 14A, B and C.

Step B indicates clearly how the material reverses to form the finished cup (step C).

## COMBINED OPERATIONS

Blanking, first draw, second draw, and finishing operations, can, sometimes, be combined into a single tool and be performed successively during a single downward and upward stroke of the press. When it is not possible to finish a part in one press operation, successive draws can be achieved in different ways.

### a. Press Transfer

The parts drawn in the first operation are transferred manually or automatically to the following tool mounted on another press.

### b. Parts Transfer

The part drawn in the first operation is automatically transferred through the use of fingers, suction cups or other devices to another station of the same tool or to another tool mounted on the same press. The number of stations or tools will correspond to the steps necessary to finish the part.

### c. Web Carrier

In this system, the parts formed on the first draw are not severed from the material strip in such a way that the movement of the strip from one station to another automatically transfers the part. The last operation will completely trim the part from the web and eject it.

Very little work has been done to date on progressive tools using part transfer or web carrier for Cycopac and Cycolac MS drawing. However, it looks quite feasible, if forming sequences are adequately developed.

### d. Combining operations on a single station, which is highly desirable for large volume applications such as packaging, have been successful using Cycopac 155.

A description of two of these tools follows.

#### 1. Combination First and Second Draw

The combination is particularly interesting to save one operation in drawing a part from a relatively low ductile material or for making a cup having a low diameter-to-thickness ratio.

Such a tool is shown schematically in Figures 15A, B and C.

The first draw is done using tool designed with a spring loaded draw ring die (see Figure 11B) and the second draw is done as an inverted redraw as shown in Figure 14.

The limitations of this system are in the size of the parts that

can be made, because of the necessity of a long stroke and shut-height on the press.

## 2. Combination of Blanking, Drawing, Wiping, Coining and Curling

A cross-section of the die making the cup shown in Figure 16 is outlined in Figures 17A and B. The right side of Figure 17A represents the upper position. The left side shows the down stroke position of the press. Figure 17B represents the situation of the components at mid-stroke.

The first operation (blanking) takes place when the shearing edge of blanking punch (8) contacts the material laying over the shearing member (4). A circular blank is then cut out and pressed between the die (8,9) and the draw rings (5 and 14). Due to the pressure maintained into the chamber (15) of the upper member, and shoulder provided by the ring (8) on the die member (7), the two pieces (8 and 9) start moving down simultaneously. The draw ring (5) through the pressure of the air cushion and the shoulder located in its lower portion, maintains the sleeve (14) in the position indicated on the drawing (right).

As the press continues its stroke down, the material starts to form around the punch (6) and the dies (8 and 9), the draw ring (5) and the sleeve (14) move down simultaneously until the sleeve (14) bottoms on the base (1) of the tool as shown in Figure 17B. At this moment, a cup with a flat flange is formed and the material is strongly pressed between the sleeve (14) and the die (9).

Continuing the stroke down, the flat flange of the cup is wiped down around the sleeve (14) which acts as a drawing punch, the inner face (of die 8) acts as a die. A shoulder on the cup is thus formed until the press arrives at down stroke.

At this moment, the knock-out pad is forced "solid" against the punch, coining the material and forming the bottom shape of the cup.

When the press starts its motion upward, the contact between the sleeve (14) and the die (9) is maintained by gas pressure in the chamber (15), and only the draw ring (5) and the die (8) are moving simultaneously.

During this movement, the material which has been wiped around the sleeve (14) during the down stroke is forced to shape into the toroidal chamber provided partly in the draw ring (5) and the die (8), forming the desired curl around the top of the container.

When the die (8) shoulder hits the corresponding shoulder on the die (9), both parts start to move on draw ring (5), hits the corresponding shoulder on the sleeve (14), and consequently all four parts (8,9,5,14) move up together with the formed container. In a conventional manner at the top of the stroke, the knock-out rod hits a fixed bar located on the press and ejects the container from the die.

Two important design features on that tool should be mentioned.

- a. A step .060 wide x 0.10 high is provided at the bottom of the die (8) on its periphery, in order to limit the holding pressure at the end of drawing and avoid excessive squeezing of the material and possible formation of tiny chips that will remain in the die.
- b. The diameters of the semi-circular grooves, located respectively on the draw ring (5) and the die (8) must be carefully established, depending upon the thickness of the material and the diameter of the desired curl, the diameter of groove on (8) being always smaller than the groove on the draw ring (5), as shown in Figure 17B.

#### TOOL DESIGN PARAMETERS

The tool design parameters for drawing ABS circular shapes have been published recently.<sup>2</sup>

- a. Punch radius 4 to 15 times material thickness and depends generally upon the configuration of the part to be made.
- b. Die radius 4 to 10 times material thickness.
- c. Clearance, as space between punch and die, should be maintained as a minimum determined by sheet extrusion tolerance.
- d. Surface finish of tool components is particularly important for the section of draw ring and the die that are in contact with the material during the draw. An 8-micro-inches finish, directly obtainable from grind machines, has given satisfactory results.
- e. Venting of all parts of the die which may promote air entrapment, is of primary importance, particularly in forming thin Cycopac or Cyclolac sheet, in order to avoid distortion, thinning or fracture.

Figure 18 shows the relationship between the punch radius, the die radius, the clearance and the sheet thickness, and a new dimension (G), which can be called the air gap, and is the radial distance where the material is not confined at the beginning of the draw.

$$G = R_D + R_P + t + C$$

where

G = air gap  
R<sub>D</sub> = die radius  
R<sub>P</sub> = punch radius  
t = sheet thickness  
C = clearance

In order to avoid formation of wrinkles that will be difficult to iron out, the air gap should be maintained as low as possible, which generally means that all radii and clearance should be as small as the operation permits. As soon as the draw starts, it

can be seen that the air gap reduces immediately to a value close to  $t+C$ .

## OPERATING PARAMETERS

Operating parameters have been discussed in a previous paper,<sup>1,2</sup> such as:

- a. The drawing speed has been found practical between 40 and 120 strokes per minute.
- b. The draw ring pressure (or holding pressure) is considered one of the most important factors for successful deep drawing and should be 50 to 400 psi, depending upon the area of the blank in contact with the draw ring at the start of the draw.
- c. Lubrication is absolutely necessary for deep drawing ABS and it has been found that both sides of the sheet should be lubricated. Some lubricants used for metal drawing have given satisfactory results for drawing ABS, but are somewhat difficult to remove, particularly mineral oil. Experiments have been conducted using waxes, fatty acids and fatty esters, mixed on both water emulsions and solutions in various solvent compositions, in order to have the possibility of coating the sheet prior to drawing and to retain a relatively small quantity on the surface to permit drawing, but not require removal, even for food packaging operations. Commercial formulations are actually in the last stage of development.<sup>17</sup>

## TOOLING FOR NONCIRCULAR SHAPES

Forming of noncircular shapes, from square or rectangular to very complex contours, cannot really be considered deep drawing as defined above. An imaginary part of complex shape is shown in Figure 19. Forming of this part is the result of a combination of drawing, bending and stretching which makes very difficult the determination of the sequence of operations and blank shape and size.

Although little work has been done to date in forming odd shapes from Cycolac or Cycopac, a few general statements can be made as a guide to approach the problem.

1. Make a determination of maximum stretching which will take place during the forming from the blank to the finished part. The method proposed by Stuart P. Keeler<sup>4</sup> consists of printing a grid of small diameter circles on the sheet blank before forming. This permits the determination of not only the location of the zones of maximum strain, but also the magnitude and orientation of the stretching. Such a grid is shown in Figure 20.
2. After determination of high-strain zones, the sequence of operations to get to the final shape is established, trying to spread the stretching over areas as large as possible.
3. It is sometimes possible to achieve the stretching over the desired area and control the motion of the material during the draw by using restrictors on the draw pad. The use of a flexible draw pad has also been mentioned.

4. The blank shape and size can be determined approximately by calculations for most of geometrical shapes, but for very complex contours, the "cut and try" method must be used.

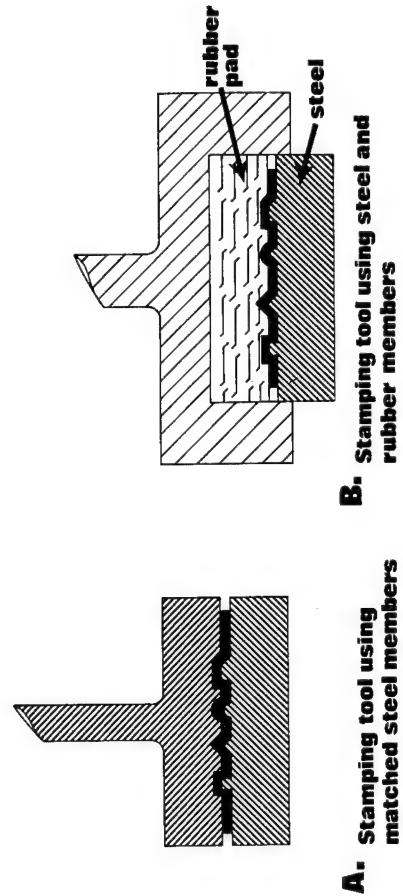
## CONCLUSIONS

The results obtained to date have established that the ductility range of Cycopac and Cycolac ABS compounds can be used for successful forming of various shapes using the metal working techniques.

Although some problems remain to be solved, such as dimensional stability at elevated temperatures and stress whitening in certain colors, it is expected that cold forming of ABS will become a commercial success through the development of new compounds, new forming technologies and special equipment, in order to relate the forming process more closely to the physical properties of the plastics materials.

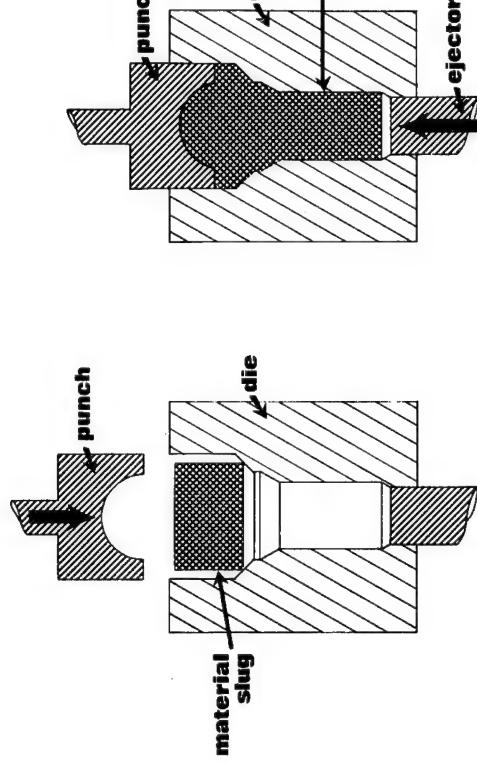
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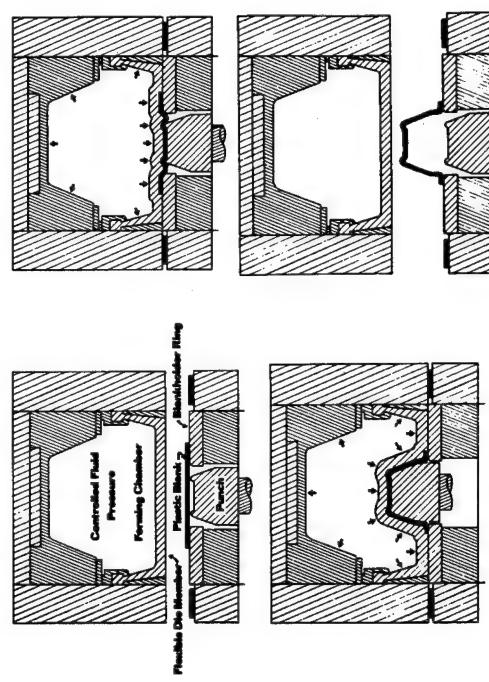
### STAMPING TOOLS

FIGURE 1



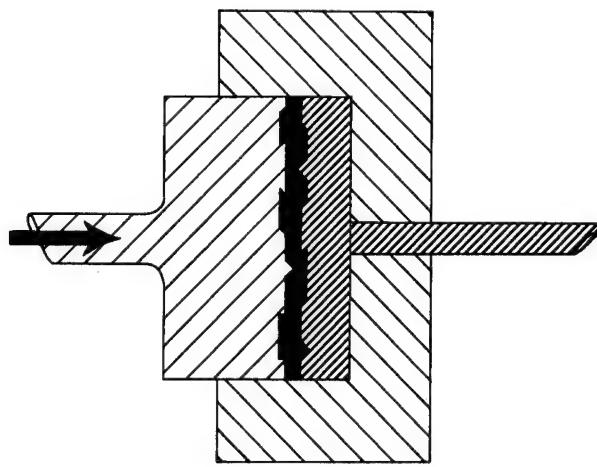
### COLD HEADING TOOL FOR A KNOB

FIGURE 3



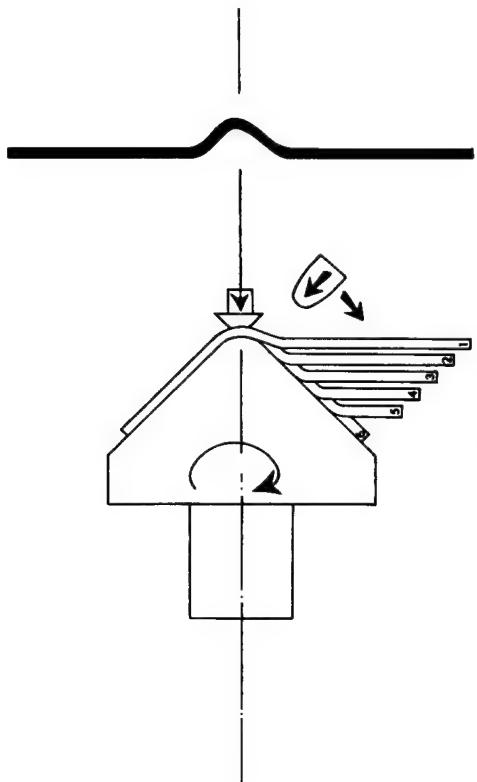
### COINING TOOL

FIGURE 2



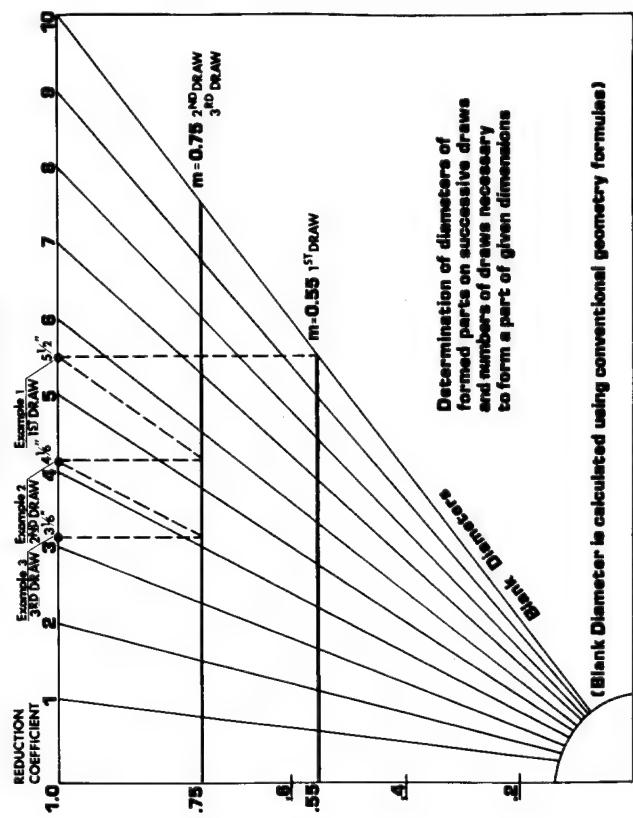
### FLUID FORMING PROCESS

FIGURE 4



**SPINNING**

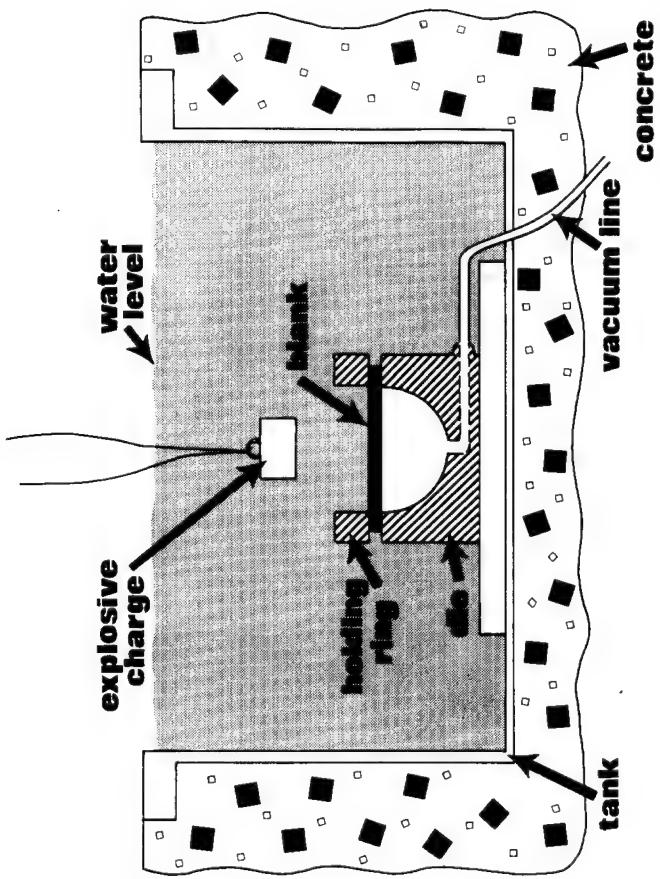
FIGURE 6



Determination of diameters of formed parts on successive draws and numbers of draws necessary to form a part of given dimensions

(Blank Diameter is calculated using conventional geometry formulae)

FIGURE 9



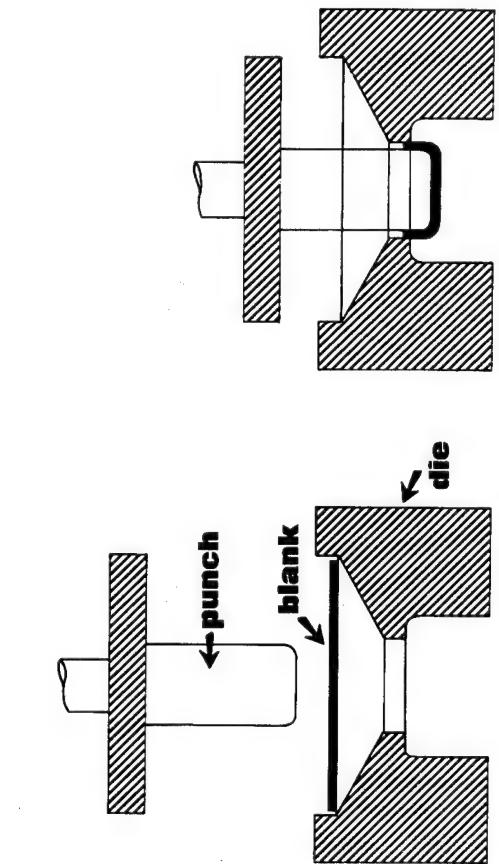
**EXPLOSIVE FORMING**

FIGURE 5

### Mechanical Properties of Metals and ABS Used in Deep Drawing

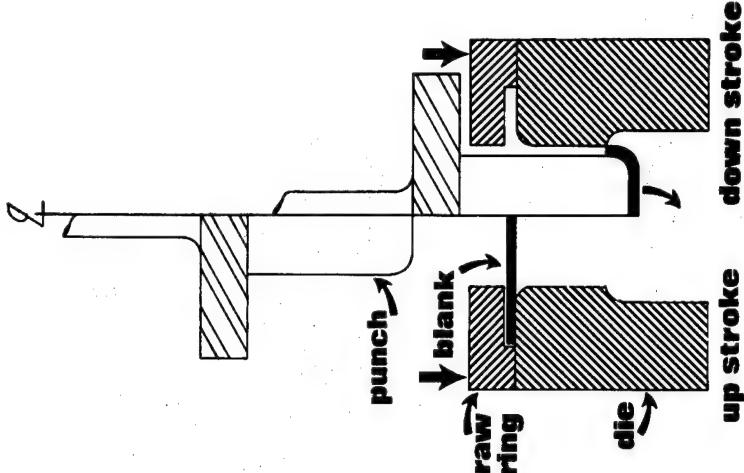
	Yield stress psi	Shear stress psi	Tensile stress psi	Elongation at break %	Young's modulus $\times 10^6$
Aluminum & Alloys	8,000 - 37,000	8,000 - 29,000	13,000 - 36,000	35-45	$10 \times 10^6$
	4,000-120,000	22,000 - 52,000	33,000 - 60,000	46-68	$13 \times 10^6$
Brass	35,000 - 90,000	34,000-150,000	42,000-120,000	10-48	$30 \times 10^6$
Carbon Steel	6,000	6,000	6,000	5 yield 25	$3 \times 10^5$
Cyclocast MS	6,400 - 6,800		68,000	6 yield 25	$3.5 \times 10^5$
Cycopac 155					

FIGURE 7



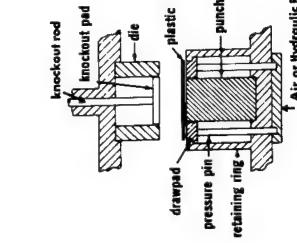
**THE SIMPLEST DRAWING TOOL**

FIGURE 10



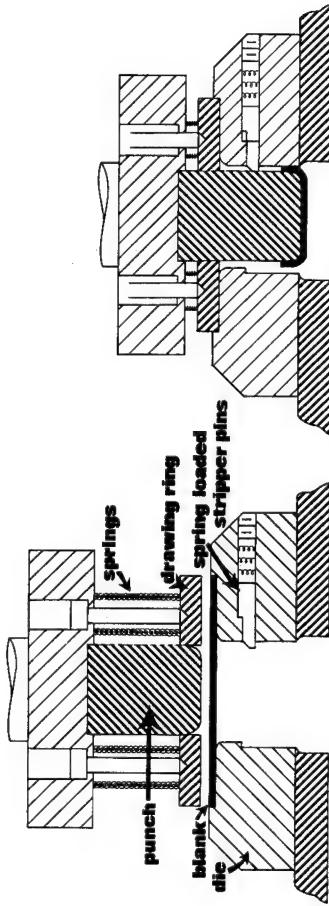
## POSITIVE DRAW RING USED FOR DRAWING THICK MATERIALS

FIGURE 11a



**First Draw**  
(shown at three stages)

FIGURE 11c



**SPRING-LOADED DRAWING RING**

FIGURE 11b

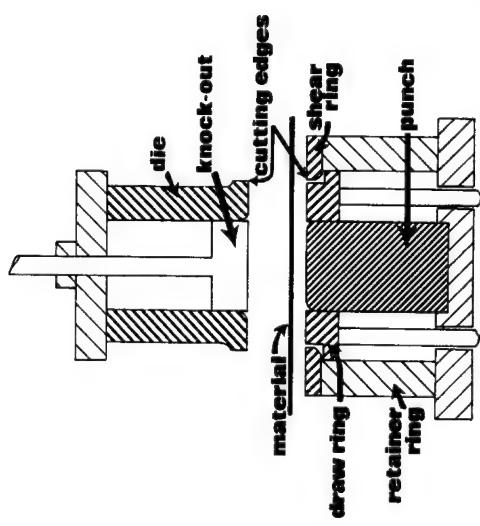


FIGURE 12

### Second Draw STRAIGHT

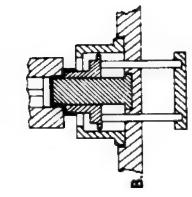
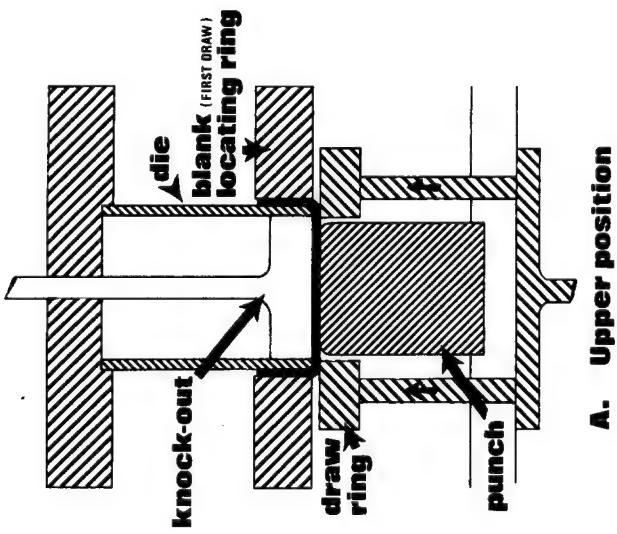
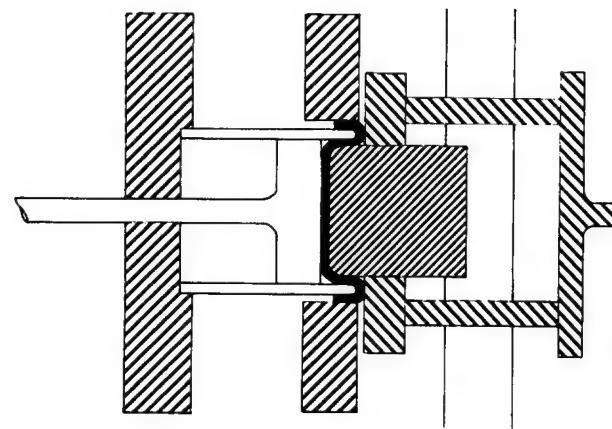


FIGURE 13

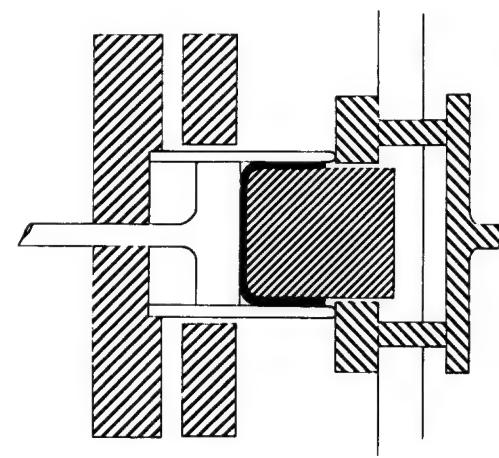
## BLANKING AND DRAWING TOOL



A. Upper position



B. Position at mid stroke showing how the cup is being reversed



C. Position at down stroke

FIGURE 14a

FIGURE 14b

## INVERTED REDRAW TOOL

FIGURE 14c

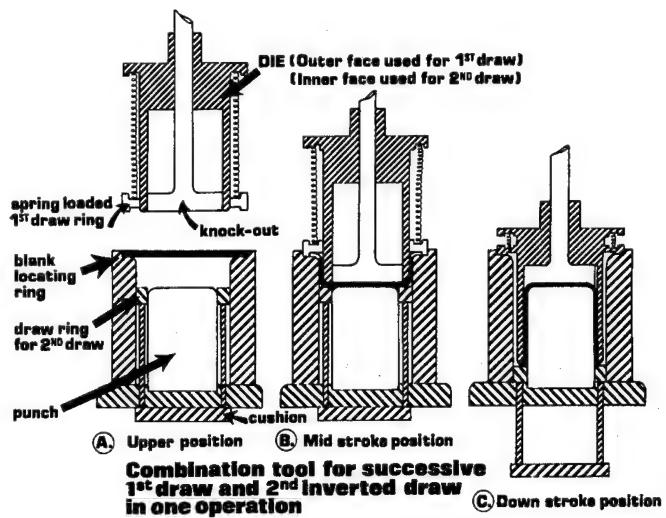


FIGURE 15

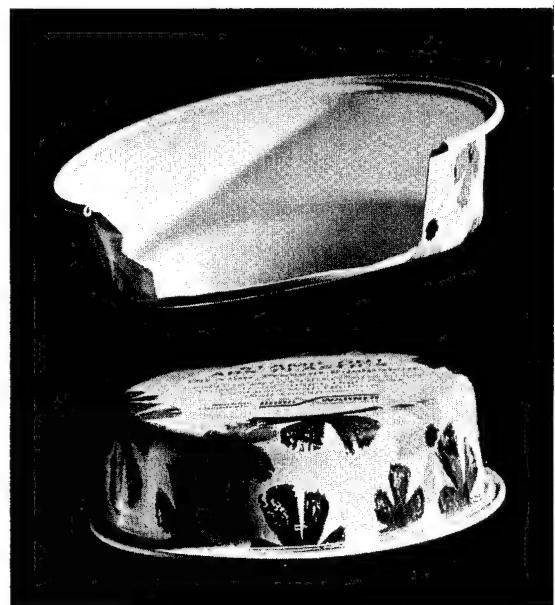
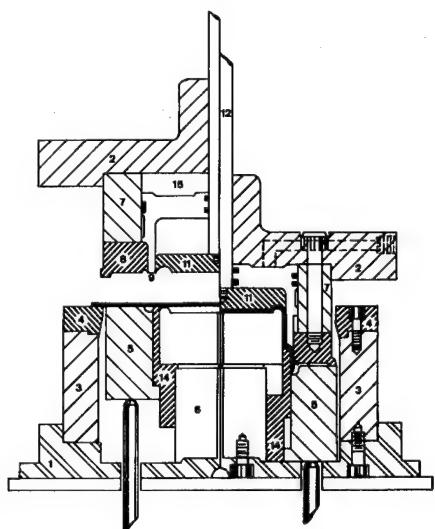
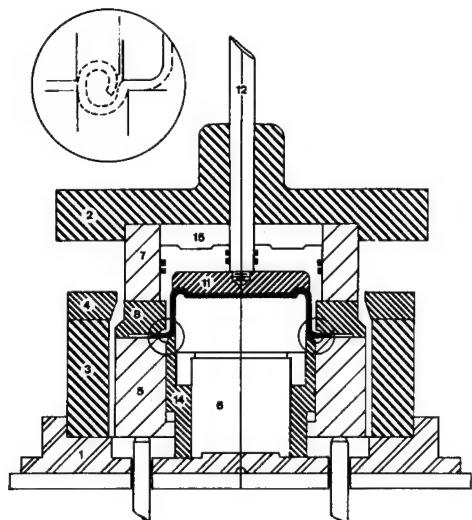


FIGURE 16



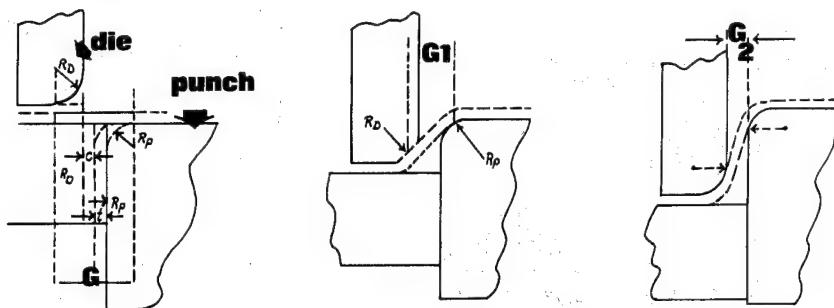
**TOOL FOR COMBINATION BLANKING,  
DRAWING, WIPING, COINING & CURLING  
SHOWN AT LEFT IN UPPER POSITION  
AND AT THE RIGHT IN DOWN STROKE POSITION.**

FIGURE 17a



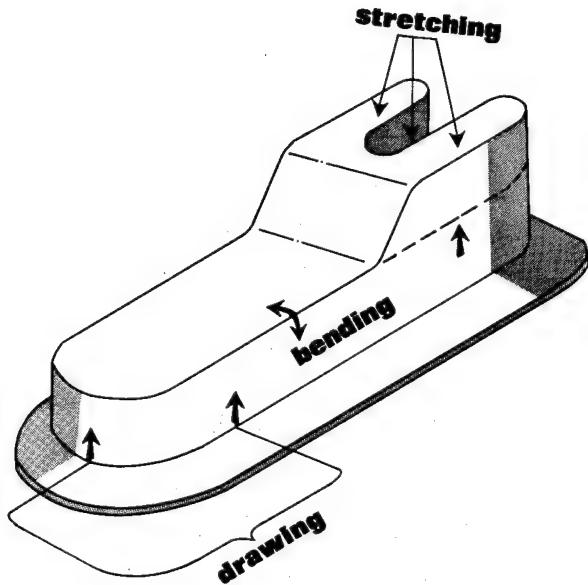
**MID STROKE POSITION  
OF COMBINATION TOOL**

FIGURE 17b



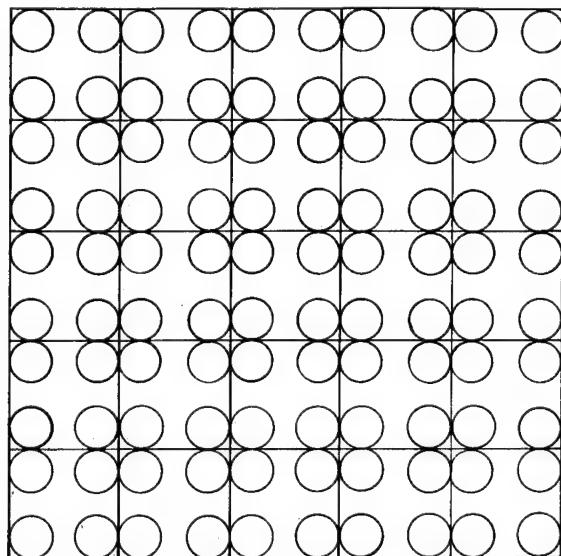
**RELATIONSHIP BETWEEN PUNCH RADIUS, DIE RADIUS AND CLEARANCE, SHOWING VARIATION OF AIR GAP (G) FOR VARIOUS POSITIONS OF THE PRESS**

FIGURE 18



**Complex shape with a combination of drawing, stretching and bending.**

FIGURE 19



**Grid with circles, printed on the sheet for determination of highly strained zones on a formed part.**

FIGURE 20

## PRINCIPLES OF POLYCARBONATE VACUUM-FORMING

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## INTRODUCTION

The growing demand on the plastics industry today has resulted in a trend toward materials with more sophisticated properties that demonstrate overall capabilities close to those of metals. Polycarbonate is a product of this sophistication. Heat resistance under load, dimensional stability, self-extinguishing characteristics and exceptional impact strength are among polycarbonate's attributes. The introduction of new thermoplastics such as this has also brought increased attention to the process of thermoforming. This mode of fabrication lends itself perfectly to the production of thin-walled parts, large parts and simplified low-volume production. The purpose of this paper is to present thermoforming considerations as they relate to polycarbonate sheet.

## DISCUSSION

### A. Forming Techniques

Polycarbonate sheet can be formed using conventional techniques. Factors to be considered in identifying the best technique include: material distribution, surface definition, undercuts, depth of draw and critical dimensions. Generally speaking, the cycle should be as basic and simple as possible and still meet the application's requirements. Much time and effort could be wasted, for example, if the sheet is prestretched unnecessarily.

Two of the least complex techniques are straight-forming into a female mold and drape-forming over a male mold. The former technique provides detail on the part exterior and also allows some freedom with undercuts and minimum draft. Since the vacuum seal is created at the lip of the cavity rather than the perimeter of the mold base, there is usually a significant reduction in available forming material. This results in excessive thinning in many instances. Polycarbonate sheet is usually limited to a maximum depth to diameter draw of 1:2 with this approach. The effects of mold depth on material distribution are illustrated in Figure 1.

Wall uniformity can be improved by employing drape-forming in deeper draw situations. An increase in the effective blank size and the addition of a prestretching step as the material is draped over

the mold account for this improvement. Depth to diameter ratios in the range of 1.5:1 are possible with polycarbonate. Maximum wall thickness develops at the top of the mold, while the minimum occurs where the mold joins the base. A comparison profile of male and female forming is shown in Figure 2.

Inverted drape-forming offers the same advantages as conventional draping with one important advantage. During the heating step, the material is allowed to sag, thereby inducing additional pre-stretching. Normally, thinning at the mold base intersection will be reduced to a minimum as the material is drawn over the mold.

Snapback and bellow-forming are among the more popular, sophisticated polycarbonate forming techniques and are ideal for thin-wall, deep draw parts. Both involve a forced stretching operation, either by pressure or vacuum. Molds and plugs should be heated to delay the polycarbonate cooling cycle and thereby reduce the chance of premature chilling. Mold temperatures in the 200-250°F range are suggested. Air temperatures used in bilowing may also have to be increased with thinner gages or when lengthy forming cycles are involved.

#### B. Molds

A wide variety of mold materials are acceptable for polycarbonate thermoforming. These include: hardwood, plaster of Paris, metal-filled epoxy and metals. Each differ in the areas of material cost, durability and ease of fabrication. Selection should, therefore, be based on these considerations.

One of the most inexpensive of materials is wood. Maple, close-grain mahogany, birch and oak all exhibit the proper degree of hardness and are suitable for limited production runs. Laminates should be constructed with the inter-layers situated horizontally or parallel to adjacent heating banks. This will minimize direct radiation and add to the life of bond. Common varnish, paint and shellac finishes should be avoided because of their tendency to bubble or stick. Solvents in many of these finishes will also attack polycarbonate. A smooth, untreated wood surface is usually satisfactory. The useful life of a wood mold is dependent upon cycle frequency. A control of heat absorption or buildup is essential for maximum yield.

Plaster of Paris is also an easy to work with material that is useful in producing simple molds quickly. Plaster is particularly suitable for prototype work and short runs of about 25 (maximum). When casting is feasible, the consistency should be such that it will pour readily. This will also provide maximum surface definition as well as additional handling time. A release agent, such as silicone spray, should be applied to the control part's surface to reduce the chance of adhesion. Application of the release agent should be smooth and free of bubbles. Curing times will vary with plaster thickness. Massive sections may require a period of two weeks at room temperature. A core of wood has been used successfully to reduce both the mold weight and setup time. Vacuum holes can either be drilled or cast directly using piano wire, coated with silicone grease.

Aluminum-filled epoxy combines the advantages of casting with the ability to dissipate heat readily. Protective gloves and safety goggles are recommended during handling. High quality mold finishes and ease of machining are also common to metal-filled epoxies. Aluminum powder formulations up to 50 per cent reduce heat buildup to a minimum in heavy mold sections. See reference<sup>1</sup> for more detailed information.

Probably the most common and most acceptable molds for thermo-forming polycarbonate are those of steel and aluminum; the latter performing best when heat dissipation is crucial. Rapid cooling and heating, maintenance of critical dimensions and durability are among the obvious advantages. Metal molds are not usually justified for low-volume production due to relatively high machining costs.

Once the mold material has been selected, certain mold design parameters must be considered. As with other thermoplastic materials, polycarbonate will achieve its best material distribution when generous radii are available on the mold. This is particularly true with deep molds. Abrupt changes in contour usually result in unnecessary, localizing thinning. Generally, the use of minimum radii that have twice the material thickness is a good rule of thumb for material thicknesses above 1/8 inch. Upper radii on shallow male molds can be as little as 1/16 inch.

Stripping of a formed part from the mold is, for the most part, affected by draft angles and mold finish. A minimum draft of 3° and a mold finish in the 5-10 inch range is recommended with polycarbonate. Draft angles also play an important role with female molds, in that material distribution is enhanced with increased pitch. A number of lubricants can also be used to improve part ejection. Silicone spray, Teflon spray, zinc stearate and molybdenum disulfide have been found to be quite satisfactory. Parts should not be allowed to remain on the mold too long because high interference stresses can lead to stress cracking.

Critical part dimensions rely heavily on predictable material shrinkage. Polycarbonate's mold shrinkage varies only slightly, with a range of 0.006-0.008 inch/inch. This narrow span, coupled with dimensional stability, make polycarbonate a very desirable material for close tolerance applications.

Vacuum holes should be situated in such a manner as to insure total evacuation. Detailed sections, such as grooves and bosses, normally require special vacuum considerations. Vacuum hole diameters should be approximately 0.015 inch to 0.020 inch for minimum appearance or definition problems. Back drilling with larger drills is suggested for efficient evacuation.

Although heated molds are not generally required when forming polycarbonate sheet, they can contribute significantly to surface quality and to the fabrication of deep draw parts. Mold temperatures between 200-250°F are suggested for deep draw and plug assist situations. Critical appearance parts may require levels up to 295°F. Heated molds also facilitate part removal since

total shrinkage is restricted during the ejection stage.

Molds can be mounted on simple boxes, fabricated from pine two by fours and standard grade plywood. These materials are not susceptible to charring at normal forming temperature. When mounting several male molds, particularly truncated molds, on a single base, it is advisable to provide a minimum spacing equal to 1-3/4 times the mold height. Less separation can lead to bridging and/or webbing of excess material. Blended male contours are not as vulnerable in this sense and may allow tighter spacing. For even closer spacing, a rod or strip assist should be used.

#### C. Forming Considerations

Polycarbonate is an excellent forming material, possessing a wide plastics range through which to work. Of the various polycarbonate materials available, there are only two that exhibit basic differences in forming characteristics. These might be categorized as general purpose grades and improved forming grades. The former are quite acceptable for the majority of thermoforming applications. However, for difficult parts, i.e., deep draw, complex shapes, close spacing, etc., there is some tendency for the general purpose grade to web, and in those cases where higher forming temperatures are necessary, sagging can also be expected with the general purpose material. Improved forming grades maintain flatness during the heating cycle and significantly reduce webbing tendencies (see Figure 3). Greater tensile strengths at forming temperatures also result in improved material distribution.

Polycarbonate, as with most other plastics, will absorb some degree of free moisture. Polycarbonate is also identified as a hygroscopic material, indicating that absorbed moisture will become chemically bound. Other hygroscopic materials include: ABS, nylon, acrylic and polysulfone. Typical polycarbonate water absorption values are as follows: 0.15% per cent (equilibrium) in an environment of 50 per cent humidity at room temperature, 0.35 per cent (equilibrium) when immersed in water at room temperature and 0.58 per cent after ten hours in boiling water. Despite these low values, polycarbonate requires thorough drying before forming. Failure to do so will result in bubbling as shown in Figure 4. Recommended drying techniques are listed in Table I. Neither the indicated temperatures nor the absorbed moisture will adversely affect physical or chemical properties. When drying polycarbonate, it is advisable to hand sheets separately for optimum drying effectiveness. Stacked sheet does not permit satisfactory surface drying. A typical drying arrangement is shown in Figure 5. Drying should be scheduled so that the material will be formed immediately after it is removed from the oven. This can significantly reduce total cycle times.

Following the drying step, the blanks should be free of dust and dirt. Should proper cleaning be overlooked, permanently imbedded particles can result. This is true of most thermoplastics and is caused primarily by static buildup. Simple wiping with a clean cloth is not usually effective and tends to push the particles

around rather than remove them. The application of ionized air has been found to be the best approach. In this way, particles are repelled with a minimum of effort. Antistatic agents applied with a cloth are suggested following the forming operation.

The broad range of plastics deformation exhibited by polycarbonate results in a relatively wide range of acceptable forming temperatures. Generally, the values lie between 340-400°F. Such variables as webbing, detail, optics, gauge and part complexity must be considered in determining optimum conditions. For example, in the lower range of temperatures, the chance of webbing is minimum but little detail can be expected. Since the process of thermo-forming is, to a great degree an art, the proper balance of forming conditions must be established empirically. Another consideration is the rapid cooling rate of polycarbonate. This can be both an asset and a liability. An asset from the standpoint the total forming cycle may very likely be shorter than most other thermoplastics. A liability in the sense that practical handling or forming time is critical and if not completed rather quickly, will result in cold forming. Again, experimentation within the outlined conditions is recommended.

Mold configurations play a major role in determining the conditions of any forming cycle. One of these conditions is drape speed. Drape rates between 4 to 10 inches/second are quite acceptable for typical female molds and shallow male molds. The range should be reduced to 4 to 6 inches/second for deeper male molds so that the chance of webbing is reduced.

Forming characteristics of a given mold configuration can be improved by the addition of ring and strip assists. Essentially, their function is to take up excess material in critical areas, thereby minimizing the chance of material folding on itself. Limited experimentation indicates that ring assists should be approximately two times the diameter of the mold, with an approximate height equal to 1/4 to 1/3 the mold diameter.

Hot bending of polycarbonate can be accomplished with very little difficulty. Stock temperatures in the range of 300-325°F must be strictly controlled, however. Temperatures greater than 325°F will result in the formation of moisture bubbles. Should higher temperatures be necessary, then the sheet must be dried as described earlier. Nichrome resistance wire embedded in asbestos sheet has proven to be a simple and effective device for bending. A Variac is suggested for proper temperature control.

#### D. Secondary Operations

Formed parts can be sheared, punched, sawed, routed, drilled and tapped. Generally speaking, most common machining operations can be applied to polycarbonate. Several basic rules should be recognized, however. These include: the use of sharp tools, close tolerances between cutting faces, high tool speeds, relatively slow feed rates and the avoidance of cutting oils containing non-compatible additives. Air and water mist has been used successfully in those situations where cooling was required.

Bonding can be accomplished with solvent and adhesive systems, as well as with ultrasonics. Material suppliers should be contacted regarding recommended bonding systems, characteristics and procedures.

Polycarbonate can also be painted, printed, vacuum metallized, plated and silk screened. As with other thermoplastics, compatible coating systems must be used to avoid stress cracking.

#### SUMMARY

The selection of polycarbonate sheet, particularly in high-performance applications, has become quite common. It is apparent, with this increased acceptance, that minor thermoforming differences have not proven to be prohibitive. High-quality parts are easily produced when proper handling and forming techniques are practiced.

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2. Zelnick, D., "Thermoforming - The Process and the Machinery", Vol. 8, No. 5, May 1968, pp. 12-15.

#### ACKNOWLEDGMENT

The author wishes to thank the General Electric Company for its permission to write and present this paper.

TABLE I

POLYCARBONATE SHEET DRYING TIMES AT 257°F (125°C)

<u>Sheet Thickness, (inches)</u>	<u>Drying Times</u>
.010-.030	15 minutes
.040	30 minutes
.060-.080	2 hours
.100-.125	5 hours
.187	13 hours
.250	24 hours

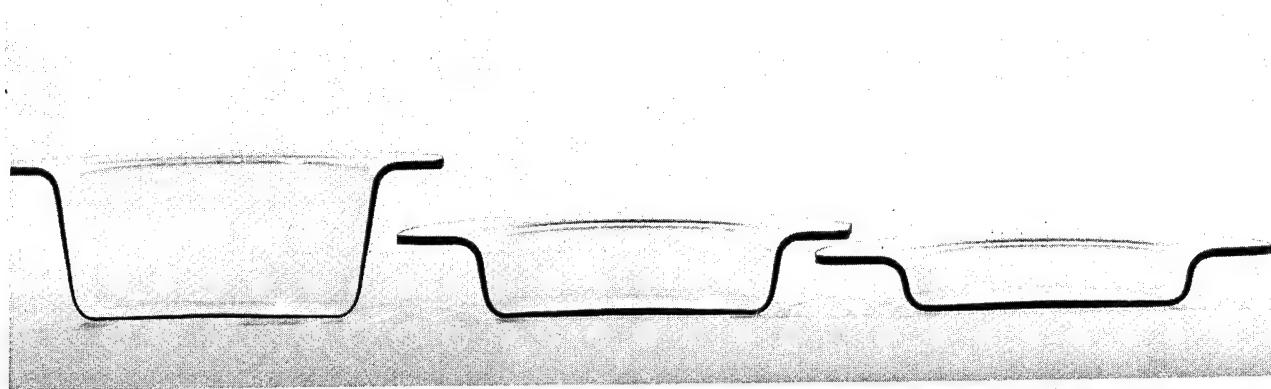


FIGURE 1: The Effects of Mold Depth on Material Distribution

TYPICAL PROFILE COMPARISON BETWEEN MALE AND FEMALE MOLDS

DEPTH:DIAMETER 1:2 ORIGINAL SHEET THK. 93 MILS  
(MEAN MOLD DIA. 3.5 INCHES)

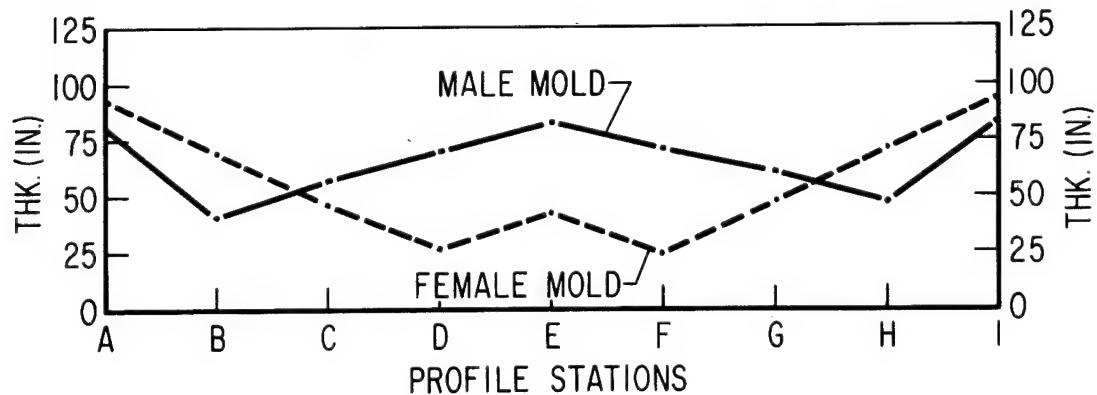
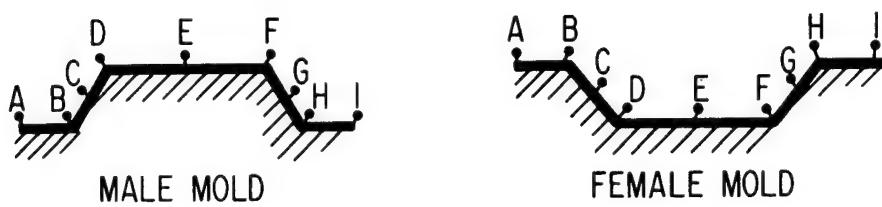
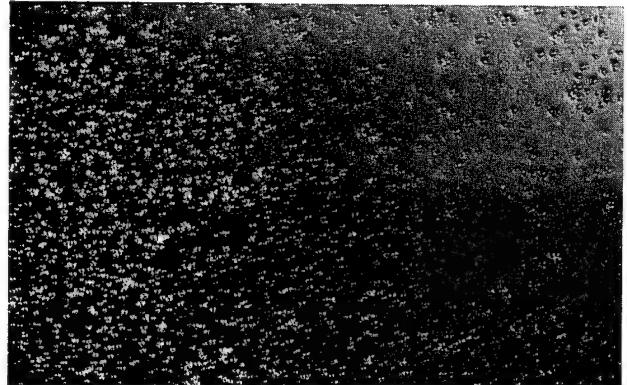


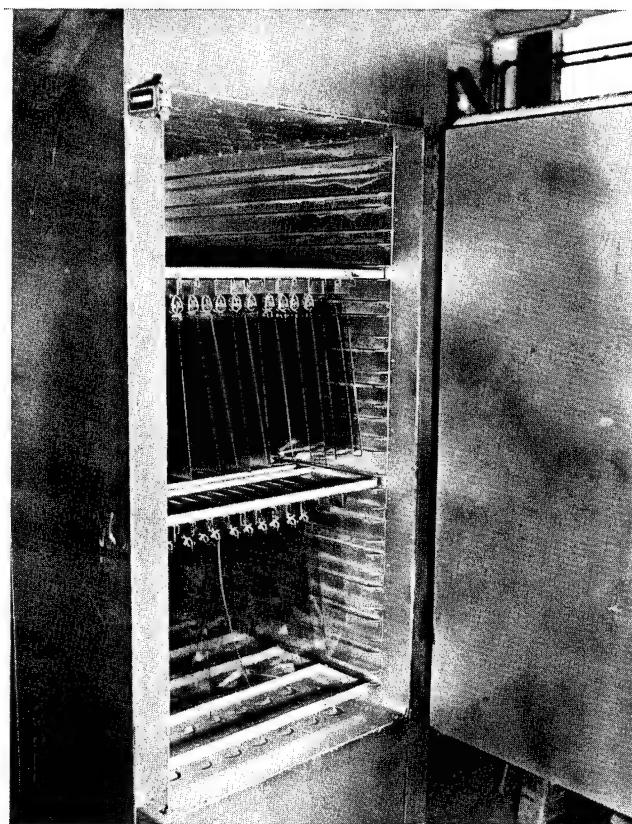
FIGURE 2



**FIGURE 3: Webbing is Eliminated Using Improved Forming Grade Polycarbonate (Top)**



**FIGURE 4: Moisture Bubbles Which Develop in Undried Sheet at Forming Temperatures.**



**FIGURE 5: Typical Drying Arrangement.**

A COMPARISON OF FOAMED AND ORIENTED POLYSTYRENE  
AS THERMOFORMING MATERIALS

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#### INTRODUCTION

Unmodified polystyrene is a thermoplastic resin which is crystal clear although it can be pigmented or dyed into a myriad of transparent, translucent or opaque colours. It is also a very hard material and a brittle one having a modulus of elasticity of 500,000 pounds per square inch and an ultimate elongation normally between 1 and 2 per cent. The resin is tasteless and odourless, although some of the earlier resins had a problem with residual monomer which gave the material a characteristic smell and made its use for food packaging limited. Today, resins of high purity, running 0.1 and 0.04 per cent maximum monomer contents, are standard in the industry and these will meet the most rigorous food packaging and taste transfer requirement criteria. Polystyrene resists many acids and bases although it is vulnerable to certain citrus fruit, cleaning fluids, gasoline and ketone solvents. Polystyrene has been in commercial production for about 30 years and many copolymers have been developed to modify the basic resin properties to improve impact, increase elongation, make processing easier and today a very wide range of properties is available in styrene based resins. Styrene-acrylonitrile (SAN), acrylonitrile-butadiene-styrene (ABS) and the family of plastics known as impact polystyrenes which include copolymerized and resin mixes with butadiene rubber are some of the more common copolymers in today's marketplace.

Polystyrenes lend themselves to other methods of modification which would be classed as mechanical rather than chemical and which produce plastics sheets suited for various thermoforming applications. The first, commonly known as OPS or oriented polystyrene, involves bi-axial orientation of the plastics in such a way as to retain the clarity while improving elongation and making the material more easily handled. The second, commonly called EPS or expanded polystyrene, involves foaming of the resin into a fine cellular structure which improves flexibility, cushioning and rigidity (based on pound for pound comparison) and gives substantial insulating properties. The purpose of this paper is to discuss the latter two materials as thermoforming substrates.

In order to fully appreciate some of the requirements for thermoforming these materials it is well to review the manufacturing processes as the properties built into the sheet originally are those which must be dealt with in subsequent processing.

## MANUFACTURE OF ORIENTED POLYSTYRENE

Although various equipment and process patents have been issued for the manufacture of oriented polystyrene which combine the transverse and longitudinal orientations in one step (such as the bubble method and some complicated mechanical tenter frames where clip spacing changes during the travel through the oven), most manufacturers today use a two step sequential orienting process where the sheet is oriented first in the longitudinal direction and subsequently in the transverse direction. The process starts with a flat sheet die extrusion-casting. Since the material is brittle if allowed to cool, it must be stretched in the longitudinal direction under controlled temperature conditions and then transported into a tenter frame oven where it is stretched in the lateral direction all under very close temperature control. Although each processor keeps a tight cloak of secrecy around his processing conditions, it is generally believed that most manufacturers keep their orientation ratios between 1.5 and 3 in both directions and that heat treatment after orienting is used to control residual shrink tension within prescribed limits. As material emerges from the tenter frame the clipped edges are trimmed off and the mill rolls wound up. A line for manufacturing oriented polystyrene sheet is a massive and expensive affair and it is believed that lines are running at rates up to 2,000 pounds per hour.

Several of the manufacturers of sheet supply two or more grades. Sheet grades are based on such things as monomer content, level of shrink tension, "thermoformability", and our own company markets a grade for fabricating which will withstand the sharp bends involved in manufacturing boxes via the techniques used normally with cardboard.

The orienting process, by aligning and stretching the molecular structure in the plane of the sheet gives several property changes, one of the most significant of which is an increase in elongation by a factor of at least 3 times. The tensile strength in the plane of the sheet runs 9,000-12,000 psi and the specific gravity is negligibly changed at 1.04-1.05. This gives an area factor of 26,300 square inches per pound per mil thickness and the material generally compares favourably in stiffness and clarity with other thermoforming materials available.

## OPS THERMOFORMING

The same factors which make oriented polystyrene strong and flexible complicate to some extent the thermoforming process as the material, when heated to thermoforming temperatures, exhibits considerable shrink tension (normally 60-200 psi) and must be restrained while heating or it will try to shrink to approximate its pre-orientation dimensions. Two methods are commonly used to thermoform oriented polystyrene. The older and more conventional uses a solid heating platen type machine where the material is held tightly by clamping and air pressure against the heated platen and is then formed by introducing air through holes in the platen and/or vacuum in the cavity to form the sheet once heated. The second method uses a clamping chain in a radiant heat type oven prior to a conventional thermoforming station which can include both vacuum and pressure forming and plug assisting. The advantage of the heating platen method is the relative simplicity of the equipment and the tooling. Another advantage is the ability to cut-in-place which further reduces tooling costs. The limitations of this method include inability to draw deep containers (say beyond a 1/2-1 depth ratio), the inherently slower speeds, and the criticalness of heating platens surface condition to avoid affecting the optics of the sheet. Since sheet de-orientation under heat is a time temperature phenomenon, fast cycle times and low heats, which in turn dictate

high pressures are sometimes required in order to avoid brittleness in the final formed parts. This can be particularly true in platen heated machines where the lip area can be in contact with the heating platen for the longest period of time. Excessive de-orientation when it occurs, makes the material harder to cut without dust generation or minute fractures at the cut edge.

Some interesting work has been done to increase the depth of draw by differentially heating areas of the platen in order to get different distributions of materials in the final parts and in order to be able to draw greater depths than are normally possible. It is quite probable that over the years further improvements will be made in contact heated machines which will make them more nearly competitive in abilities and production rates with the radiant heated oven type machines. Pre-printed sheet is easier to run on a heating platen type machine as registration is more easily held and there are no shrink factors in the sheet prior to forming to be dealt with (ink selection is critical to avoid pick off).

The second method of thermoforming, using a radiant heat oven, is relatively new with oriented polystyrene. The edges of the sheet are generally held by spiked chains which prevent the web from shrinking transversely during transit through the oven and the longitudinal forces in the machine control shrink in that direction. Oriented polystyrene is a tricky material to run on machines of this type, especially where complex shapes are to be formed. If the sheet is allowed to overheat in order to form detail, it has a tendency to move under its own shrink tension and hence the equipment must be run with high forming pressures and the sheet at relatively low forming temperatures. It is reported that there is some tooling used in Europe which incorporates cut-in-place in this type of thermoforming machine but generally post trim operations are used, especially on multiple-up tooling. This adds cost to the tooling; however, the shear cut from a trim press is inherently better than that obtained with cut-in-place where there is a tendency to form slivers, unless tool sharpness and clearances are very exactly held. We currently manufacture medicine medicine cups using this type of tooling and have made drinking cups, although this latter operation is not currently commercial.

Some fabricators have coating or spraying operations in series with their thermoforming machines and anti-fog coatings or release agents can be put on the sheet in this manner. As of the time of writing there are no known food and drug approved additives to give sheet anti-fog properties via the resin addition route, although most resin manufacturers have work going on in this area.

#### MANUFACTURE OF FOAM POLYSTYRENE

Foamed polystyrene sheet is produced by the extrusion of a mixture of crystal styrene, a volatile blowing agent and a nucleating agent. The release of blowing agent from solution in the polymer occurs when its partial pressure is greater than the environmental pressure of the polymer, normally as released from the extrusion die. Structural properties of the foam, including thickness, density, cell size, stiffness, etc., are determined by a complicated relationship between the following:

- a. extrudate temperature;
- b. type and level of nucleation;
- c. type and level of blowing agent;
- d. geometrical factors of die and mandrel;
- e. linear velocities of material at die and windup.

Blowing agents are typically C<sub>4</sub>-C<sub>6</sub> straight chain hydrocarbons or chlorinated-fluorinated hydrocarbons. Nucleating agents are usually added in the form of a finely divided powder which is insoluble in molten polystyrene, thus providing nucleating sites.

Generally, the blowing agent and nucleating agent are added to crystal styrene during a fairly conventional extrusion process. This is followed either directly, or in a separate extrusion process, by a cooling process closely related to scraped-surface, heat-exchange. These are commonly referred to as the direct or one-step and two-step processes. Forming of the extrudate into a sheet is normally via the horizontal bubble process from a circular die over a sizing mandrel. Single or double slitting of the bubble followed by winding of one or two flat sheets completes the process. The limiting factor in line throughput is the inherent problem of reducing melt temperature to the 220-290°F range required for foam extrusion. Lines capable of extruding 500 pounds per hour of foam are used by most major foam producers.

#### EPS THERMOFORMING

Before discussing the use of expanded polystyrene as a thermoforming material, it is important to consider the way in which foam may be oriented during extrusion. Unlike oriented polystyrene which is oriented in two directions in a flat sheet process, the foam process has the potential for three dimensional orientation by virtue of being a cell growth process. It is the way in which these cells are subjected to physical stresses in the polymer matrix which dictates their final shapes. In the case of perfectly balanced orientation, the cell will be spherical, whereas orientation predominantly in one direction can give rise to ellipsoidal cells. A specification of say 32 inches wide, 100 mil, 5 pounds/cu.ft. density sheet can be fulfilled with sheet which, by virtue of its processing conditions, could have a variety of cell size structures and orientations. CRYOVAC has evolved an analytical method for predicting, and, therefore, controlling, the degree to which sheet will exhibit residual orientation.

One very basic requirement in thermoforming foam polystyrene is the compatibility of foam cell structure with the thermoforming application. A foam of given basis weight can range from a brittle, coarse cell foam to a flexible fine cell foam without significant changes in thickness or density. Large cells having thick walls will generally give rise to an extremely stiff but brittle foam. It is further important to recognize there is a limit beyond which cell wall thickness cannot be reduced without wall rupturing. Consequently, material for deep draw thermoforming applications can have up to four times the basis weight of meat tray foam to enable a suitable part to be made without excessive reduction of cell wall thickness.

Unlike oriented polystyrene, foam does not exhibit strong residual shrink tendencies during thermoforming. This, together with its inherent insulating properties, has required a different approach to its thermoforming. To achieve reasonable cycle times of 2-6 seconds, it is necessary to use radiant heating prior to entry into the forming operation. Forming with contact heating is possible but with prolonged cycle times, and some problems of degradation of the surface in contact with the heating platen.

In general, because of foam's superior rigidity compared to all other thermo-forming materials on an equivalent weight per unit area basis, the designs of foam containers do not require the complicated ribbing of their oriented polystyrene

counterparts. A good example of this is a comparison of foam and oriented polystyrene meat trays. As a result, it is not necessary to use forming air to achieve adequate container definition for the majority of end uses. Rather, most fabricators use either straight vacuum forming or match mould tooling with vacuum assist. The choice depends largely upon the degree to which it is necessary to control the dimensions of the final product. Since foam expands up to two times its original thickness during the heating cycle, critical dimensional requirements dictate the use of match mould tooling to avoid the variation of thickness due to differing degrees of foam expansion. The use of air pressure could be detrimental to this foam expansion.

The comments made earlier concerning the pros and cons of trimming methods for oriented polystyrene apply to a lesser extent to foam. One additional factor with foam is that its compressibility makes difficult the location of formed parts to better than  $\pm 1/16$  inch in conventional trim press operations.

#### CONCLUSIONS

< The inherent properties of oriented polystyrene and expanded foam polystyrene are induced by different manufacturing methods from the same basic polymer. As thermoforming materials they complement one another, although they do compete for certain market areas. >

The investment and technology required for sheet producing lines for either product is high compared with the investment for thermoforming equipment. Consequently, there are few sheet producers in North America but many fabricators.

< Thermoforming techniques have developed to accommodate the widely differing characteristics of oriented polystyrene and expanded polystyrene. Forming of oriented polystyrene is largely a matter of handling a rigid, high shrink material. Forming of foam requires a deeper understanding of the fundamentals of cellular structures. >

## ACRYLIC FILMS FOR SURFACING OF PLASTICS

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## INTRODUCTION

It is helpful to begin a discussion of acrylic films with a brief consideration of acrylic plastics since acrylic plastics are much more familiar materials. As might be expected, the properties of acrylic films in many respects closely resemble the properties of acrylic plastics. Acrylic plastics have been commercially available for thirty years and they represent a well-established segment of the plastics field. They are characterized principally by their outstanding weatherability and brilliant clarity. These qualities have led to their use in such well-known applications as auto tail lights, internally lighted signs and airplane canopies and windows. Compared to plastics generally, the acrylics can be considered to have good processing characteristics, good rigidity and strength, average heat softening tendencies and moderate toughness. With this very brief and generalized background on acrylic plastics, it is possible to imagine what some of the properties and applications of acrylic films might be.

Until recently, acrylic films have not been available in thin gauges (below 5 mils) or without some sort of backing. One of the problems has been that acrylic plastics in thin film form were too rigid and brittle to have satisfactory handling properties. Stretch orientation of acrylic films to toughen them has been found to be difficult and somewhat costly. Toughness can also be imparted to acrylic films by copolymerizing the monomer methyl methacrylate with other monomers to give a softer, tougher product. The use of softer acrylic monomers for this purpose tends to cause tackiness and blocking so that polymers of this type are unsuitable for making films. The copolymerization of non-acrylic monomers with methyl methacrylate detracts from the desirable properties associated with acrylic compositions. These problems have now been solved through utilization of both the structural and compositional variations available to the acrylic polymer chemist.

## KORAD C

The first commercial all-acrylic thin gauge film was introduced by the Rohm and Haas Company in late 1966. This product, known as Korad C, is supplied in clear, unpigmented form for use primarily in overlaying various substrates, including plastics and wood. The film is not highly transparent as supplied, since it has a fine-textured, matte surface finish. This matte finish permits the film to be laminated to various surfaces under heat and pressure without the entrapment of air between the film and the substrate to which it is being laminated or between the film and the press plates. During lamination the surface is smoothed out and the film becomes highly transparent.

KORAD is a trademark of the Rohm and Haas Company

Some of the more important properties of Korad C are listed in Table I. The yield for 3 mil film is 55 ft.<sup>2</sup>/lb. The mechanical properties of the film indicate that it is stiff and has very little stretch. It has good resistance to acids and alkalies, soaps and detergents and aliphatic solvents such as naphtha and other mineral thinners. Korad C is resistant to many common stains such as shoe polish and lipstick. It possesses the outstanding weatherability associated with acrylic plastics and offers protection to substrates to which it is laminated. In short, Korad C in most respects, is quite similar to a very thin sheet of an acrylic plastic.

#### KORAD A

Another all-acrylic film of the Rohm and Haas Company which was introduced in 1967 is known as Korad A. This film is supplied in a variety of colors and in unpigmented form. It is designed principally for surfacing plastics sheet, metals, plywood and other rigid substrates.

Before considering applications in greater detail a brief look should be taken at the properties of pigmented Korad A, some of which are listed in Table II. The specific gravity of this film, because of the pigmentation, is somewhat greater than that of Korad C and consequently the area factor of 3 mil white Korad A is 51 ft.<sup>2</sup>/lb. vs. 55 ft.<sup>2</sup>/lb. for Korad C. The tensile strength and rigidity of Korad A are somewhat less than those of Korad C, but it has a significantly greater degree of elongation and is a generally tougher film. The solvent and stain resistances of the two films are quite similar.

The weather resistance of Korad A film is proving to be outstanding. Figure 1 shows the results of exposures after 24 months in Pennsylvania, Florida and Arizona at a South 45° angle. Korad A film after 24 months exposure undergoes virtually no chalking or dulling and exhibits color changes of no more than 1 NBS unit as shown in Table III. Films similar to Korad A in composition and structure have now been on exposure at Bristol, Pennsylvania for nearly 6 years without exhibiting significant color change or chalking. The outstanding durability of acrylic plastics that has been observed for over 24 years leads to the expectation of a very long outdoor life for both Korad A and Korad C films.

#### LAMINATING CONDITIONS TO PLASTICS

Laminating of the acrylic film, Korad A, to plastics sheet is achieved during the polishing or embossing stage of sheet extrusion as shown in Figure 2. The available heat and pressure are sufficient to develop a film/substrate bond which resists temperature extremes, water immersion and thermoforming conditions. Typical conditions for lamination to ABS sheet are:

Substrate temperature	390°F
Roll temperature	230°F
Roll pressure	50 lbs./linear inch

Korad C has been designed specifically for use in press lamination and again excellent film/substrate bonds are achieved with only heat and pressure. Typical press conditions used to prepare laminates of calendered PVC copolymer sheet are:

Press temperature	300°F
Press pressure	500 psi
Time cycle	12 minutes

## APPLICATIONS OF KORAD ACRYLIC FILMS

As mentioned before the acrylic films are used principally for the protective and decorative surfacing of plastics, metal, hardboard, plywood and other rigid substrates. Outdoor protection of these non-plastics substrates results solely from the physical presence of the film. The extension of the outdoor use life of plastics surfaced with acrylic films may best be explained by a review of polymer degradation mechanisms. Jellinek<sup>1</sup> shows that these degradation processes are initiated by the combined effects of ultra-violet and higher energy visible radiation and oxygen. The surface film protects by absorbing UV and near UV radiation, and by reducing penetration and oxygen, water and ambient chemicals into the base plastics.

As is shown in Figure 3, Korad ACV, which contains a UV absorber, effectively blocks the transmission of ultraviolet and near ultraviolet radiation. The pigmentation in the Korad A colors further blocks the transmission of visible light. Thus, the prime factor in active free radical formation is effectively retarded. The addition of an effective antioxidant to the base plastics further inhibits radical formation due to oxidation, providing additional durability.

### USE OF FILM SURFACED PRODUCTS

The protective and decorative advantages these films offer had led to their use in the surfacing of a variety of exterior plastics products. Pigmented Korad A is being laminated to extruded ABS and thermoformed into louvered window and door shutters. Vacuum formed Korad A surfaced ABS is being used in the roof and sides of camper bodies, as pickup truck toppers and door skins for mobile homes. Roof ventilator shrouds and air conditioner housings made of vacuum formed film surfaced ABS are also commercially available. In addition, Korad A surfaced PVC and ABS are actively competing for the building fascia market.

The basis for the selection of film surfaced plastics for these applications can best be explained by the data presented in Table IV and Figure 4. Table IV shows the influence which a surface layer of pigmented 3 mil Korad A film has on the properties of a thermoformable ABS sheet initially and after 12 months' exposure in Miami.

Figure 4 demonstrates the color stability of Korad A White surfaced ABS after exposure for 6 months as compared to unsurfaced White ABS. As can be seen, the Korad A surfaced ABS exhibits no color change whereas the ABS is tending to yellow. Gloss changes and discoloration readings of Korad A White surfaced ABS and unsurfaced White ABS after 1 year exterior exposure are given in Table V. Similar appearance protection to PVC sheet is offered by Korad film.

The Korad A film does not affect the formability of a plastics sheet to which it has been laminated. Korad A surfaced ABS sheets 10" x 10" x 1/8" in size have been drawn to a depth of 14" without any rupture or delamination of the film. Embossing and forming can be done with standard equipment from simple drape units to highly automated vacuum forming equipment.<sup>2</sup>

It has also been found that Korad A film does not interfere with the reprocessing of scrap sheet and trim to which it has been adhered. Rigid vinyl and ABS sheet, for example, which have been laminated with Korad A film, can be reground and extruded to yield sheet with properties identical to those obtained with sheets made from unsurfaced, reground material.

Lamination of Korad A film to a variety of other plastics substrates has been demonstrated. Surfacing of high impact polystyrene, polycarbonates, and vinyl

plastisols as well as thermosetting high pressure laminates such as melamine laminates are performing very well in door skin and siding applications. Exposure histories on film surfaced melamine laminates show excellent results after 18 months.

The decorative aspects of surfacing plastics can be further served by the fact that it is possible to print on Korad A film. Clear Korad A film has been printed in several wood grain patterns and a marble pattern and laminated to a variety of substrates. The film has also been metallized and embossed to give a brushed aluminum appearance.

One of the areas where Korad C film has been successfully used is in the overlaying of calendered PVC copolymer sheet after it has been printed. Typical laminates of this kind are used frequently in outdoor signs. Signs of this type are tough and durable and reasonable in price when a number of identical signs are prepared so that printing costs can be kept low. The Korad C film bonds tightly to both the vinyl sheet and the printing ink to provide a crystal clear, durable surface. When signs of this type are prepared with conventional vinyl overlay films outdoor durability is limited but with Korad C film, excellent resistance to discoloration is obtained.

Korad A film is also being used in the continuous prefinishing of metals. The continuous prefinishing operation is carried out by passing a strip of metal unwound from a continuous coil first through a treating bath which cleans the metal and chemically modifies the surface to make coatings adhere. The adhesive is next applied to the metal by a roller and dried. The coated metal and film are then passed through a set of nip rolls which apply heat and pressure and the laminate is then rewound into a coil, which is later formed and cut into a variety of shapes in a second operation.

Plywood and hardboard can be similarly protected by lamination with Korad A and Korad C. With these substrates a solvent or emulsion-type adhesive is generally applied with a reverse roll coater and dried to a desired degree of tack as the board passes through an oven. The adhesive coated board and film are then passed through a nip formed by heated, pressure rolls or a hot press to form a laminate. The film provides excellent protection for hardboard and plywood surfaces which remain unchecked after rigorous water soaking and drying cycles and after outdoor exposure.

#### REFERENCES

1. Jellinek, H.H.G., "Fundamental Degradation Processes Relative to Outdoor Exposure", *Applied Polymer Symposia*, 4, 41-59 (1967).
2. Marbon Quick Reference File, No. 10, "Improved Weatherability", Marbon Chemical, Div. of Borg Warner Corp.

TABLE I  
PROPERTIES OF KORAD C ACRYLIC FILM

<u>Property</u>	<u>Test Methods</u>	<u>Terms</u>	<u>Typical Values</u>
Specific gravity	ASTM D-792-64T	Based on H <sub>2</sub> O at 23°C	1.17
Tensile strength	ASTM D-882-64T (2"/min., 4" GL)	psi	
Yield Rupture	Line Contact - Grips		7,800 6,050
Tensile elongation	ASTM D-882-64T (2"/min., 4" GL)	per cent	
Yield Rupture			3.3 11.7
Tensile modulus of Elasticity	ASTM D-882-64T (2"/min., 4" GL)	psi	360,500
Tear resistance	ASTM D-1004-61 (2"/min.)	lbs./mil	1.24
Tear propagation resistance	ASTM D-1938-62T (10"/min.)	lbs./mil	0.02
Abrasion resistance	Tabor CS-10F wheels 1000 g/wheel 1000 cycles	Weight loss (milligrams)	68
Water vapor transmission rate	ASTM E-96-63T Procedure E	Grams/24 hrs. 100 in. <sup>2</sup>	10
Water absorption	ASTM D-570-63 24 hrs. at 23°C	% Weight gain	0.7
Solvent resistance	ASTM D-543-60T Acids, bases Hydrocarbons Aromatics, ketones, esters Ethanol	7 day immersion, 75°F	Good Good Dissolves Attacked
Stain resistance	Lipstick Ink Ketchup Mustard Shoe polish	24 hrs. at 75°F 24 hrs. at 75°F 24 hrs. at 75°F 24 hrs. at 75°F 10 min. at 75°F	Good Good Good Slight stain Good

TABLE II

PROPERTIES OF KORAD A FILM

(3 mil, pigmented)

<u>Property</u>	<u>Test Method</u>	<u>Terms</u>	<u>Typical Values</u>
Specific gravity	ASTM D-792	psi	1.26
Tensile strength	ASTM D-882	psi	
at yield			5,100
at rupture			4,800
Tensile elongation at rupture	ASTM D-882	Per cent	65
Tear resistance	ASTM D-1004	lbs./mil	1.1
Burst strength	ASTM D-774	Points	45
Fold endurance	ASTM D-643	No. of folds	500
Abrasion resistance	Tabor CS-10F 1000 g/wheel	Wt. loss in mg. 1000 cycles	67
Water absorption	ASTM D-570 24 hrs., 23°C	Per cent wt. gain	1.5
Water vapor trans. rate	ASTM E-96	gm./24 hrs./ 100 in. <sup>2</sup>	7
Solvent resistance	ASTM D-543 7 days at 75°F		Swollen
Ethanol			No change
Gasoline			No change
Motor oil			Dissolved
Toluene			Dissolved
Esters and ketones			No change
30% H <sub>2</sub> SO <sub>4</sub>			No change
10% NaOH			
Stain resistance	24 hrs., 75°F		Good
Lipstick			Good
Inks			Slight stain
Mustard			Good
Ketchup			

TABLE III

TWO YEARS SOUTH 45° EXTERIOR EXPOSURE OF KORAD A WHITE SURFACED METALS

(3 MIL FILM ROLL LAMINATED WITH ARMSTRONG CORK'S J-1199 ADHESIVE)

Substrate	Exposure Site	60° Gloss		Adhesion <sup>1</sup>	Dirt <sup>2</sup>	Dulling	Chalking <sup>3</sup>	Change <sup>4</sup>
		Orig.	2 Yrs.					
Aluminum 1200S	Bristol	31	43	1	8	None	10	-
	Miami	31	27	>1, <2	8	V.slight	10	0.2
	Phoenix	31	34	1	4	None	10	0.4
Bonderite 37S galvanized steel	Bristol	33	30	1	8	None	10	-
	Miami	33	30	>1, <2	8	V.slight	10	0.8
	Phoenix	33	34	1	4	None	10	0.5
Granodine 92 galvanized steel	Bristol	36	34	1	8	None	10	-
	Miami	36	28	1	8	V.slight	10	0.6
	Phoenix	36	39	1	4	None	10	0.6

1) Adhesion: 1 = excellent, 2 = good, 3 = fair, 4 = poor

2) Dirt: 0 = no dirt pickup, 10 = dirty

3) Chalking: 10 = no chalking, 0 = severe chalking

4) Color change stated in NBS units per ASTM D-1536-58T

TABLE IV

<u>Property</u>	<u>3 Mil Korad A Clad 1/8" ABS Sheet</u>	<u>1/8" Unsurfaced ABS Sheet</u>
Tensile strength (at rupture) psi	4500	4500
Tensile elongation (at rupture), %	79	91
After 1 year, Miami	77	7
Tensile impact strength, ft./lbs./in. <sup>2</sup>	81	130
After 1 year, Miami	40	21
Flexural fatigue, cycles to fail x 10 <sup>-3</sup>	70	52
After 1 year, Miami	48	9
Izod impact strength, ft./lbs./in.		
72° F.	4.6	5.5
0° F.	1.1	1.4
72° F., after 1 year, Miami	5.0	2.4
0° F., after 1 year, Miami	0.4	0.3

TABLE V

SOUTH 45° EXPOSURE OF ABS AND KORAD CLAD ABS

<u>Exposure Site</u>	<u>Korad A White Clad ABS</u>			<u>White Unsurfaced ABS</u>		
	<u>Bristol, Pa.</u>	<u>Miami</u>	<u>Phoenix</u>	<u>Bristol, Pa.</u>	<u>Miami</u>	<u>Phoenix</u>
60° Gloss (%) Initial	84	84	84	80	80	80
6 Months	74	74	75	20	14	25
12 Months	56	67	73	13	7	9
85° Gloss (%) Initial	97	97	97	96	96	96
6 Months	97	96	99	78	69	86
12 Months	94	96	94	75	46	64
Discoloration <sup>1</sup>						
6 Months	-	$\frac{1}{2}$ NBS	$\frac{1}{2}$ NBS	-	6 NBS	6 NBS
12 Months	$\frac{1}{2}$ NBS	$\frac{1}{4}$ NBS	1 NBS	7 NBS	7 NBS	6 NBS

<sup>1</sup>) Discoloration states is NBS units per ASTM D1536-58T

KORAD-A-ALUMINUM LAMINATES  
TWO YEAR EXPOSURE OF POST-FORMED PANELS

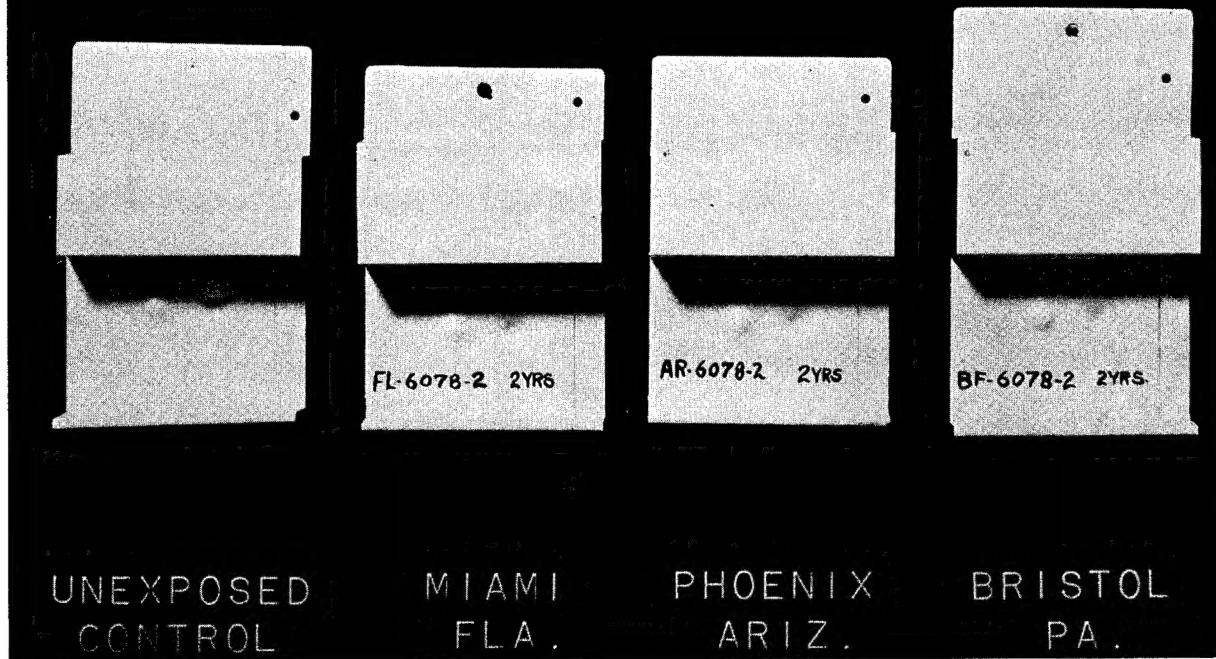


FIGURE 1

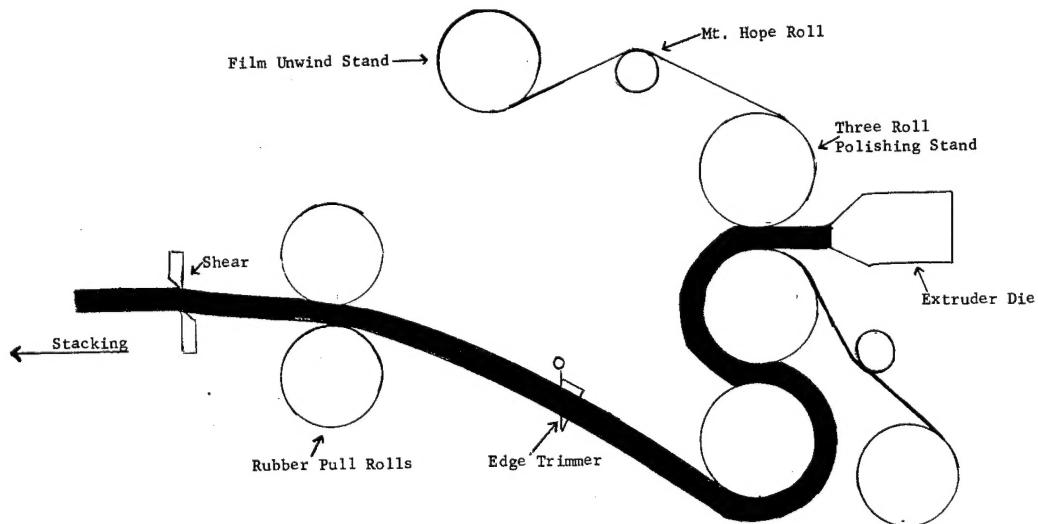


FIGURE 2: Schematic of the Continuous Surfacing of  
Extruded Plastic Sheet

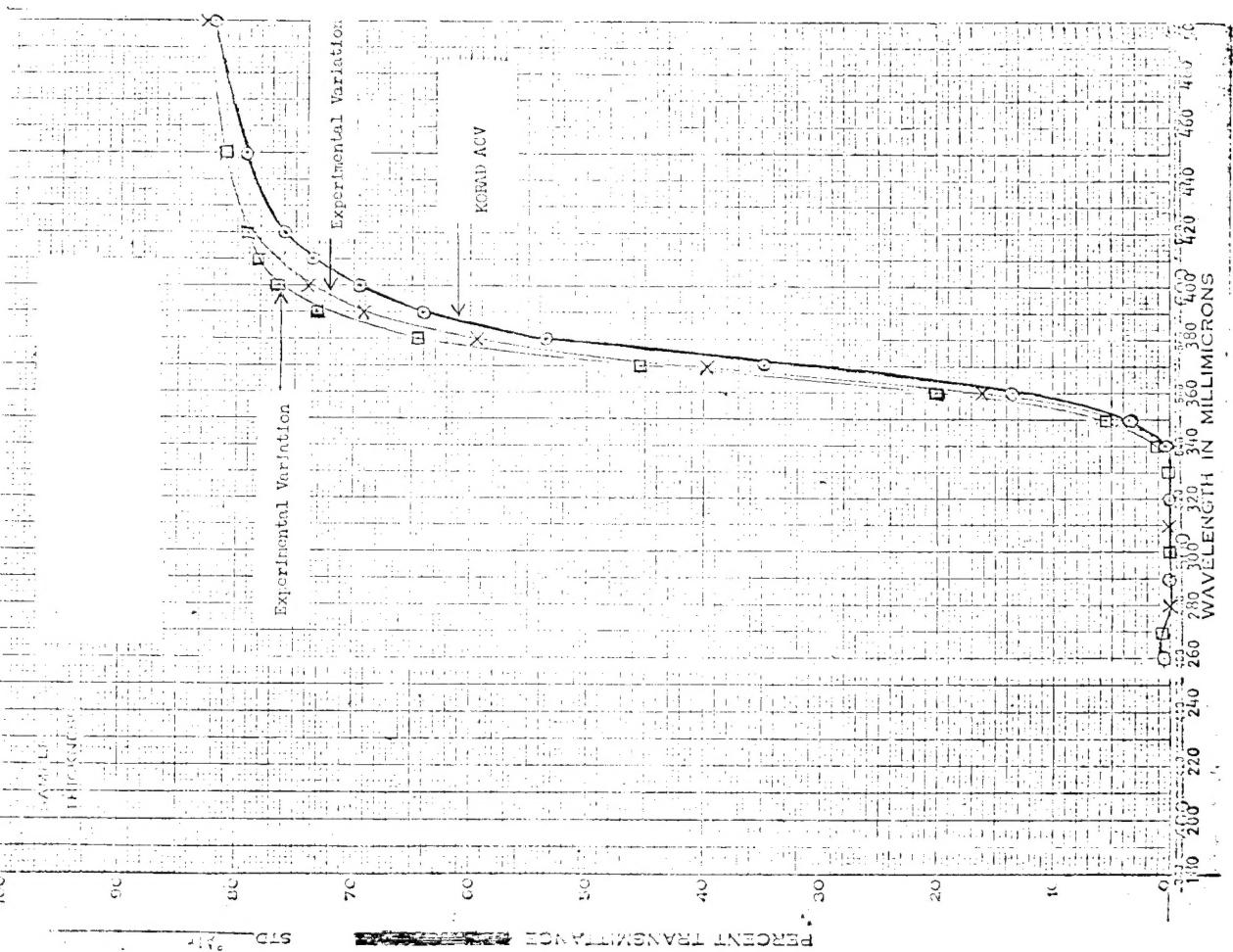


FIGURE 3: Spectral Transmission of Korad ACV

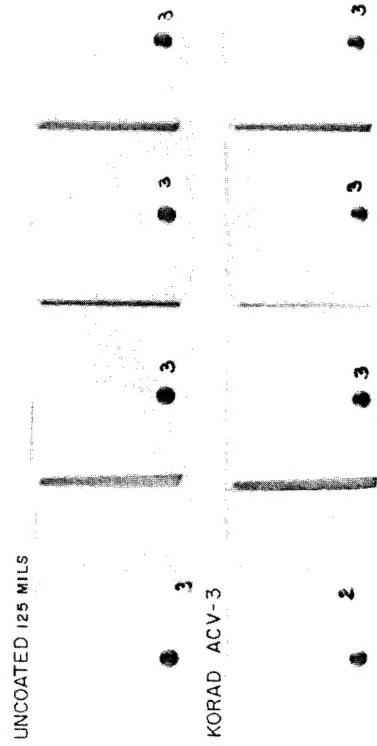


FIGURE 4

**INITIATION FEE  
MUST BE ATTACHED  
FOR PROCESSING.**



**SOCIETY OF PLASTICS ENGINEERS, INC.**

656 West Putnam Avenue  
Greenwich, Connecticut 06830

**MEMBERSHIP APPLICATION**  
PLEASE PRINT OR TYPE

**Executive Office Use Only**  
I.D. No. \_\_\_\_\_  
Ack. \_\_\_\_\_  
Elected \_\_\_\_\_

I hereby make application for  admission into  reclassification within  reinstatement in the Society of Plastics Engineers, Inc. in the grade of membership indicated below for which I believe I am qualified. (See instructions or reverse side.)

Grade	Initiation Fees	Annual Dues	Foreign Dues	I wish to affiliate with the _____ section. (Geographical location. See listing on reverse side.)
<input type="checkbox"/> Senior Member	\$10.00	\$20.00	\$17.50	
<input type="checkbox"/> Member	10.00	20.00	17.50	
<input type="checkbox"/> Affiliate Member	10.00	20.00	17.50	
<input type="checkbox"/> Student Member	None	5.00	5.00	

Applicants Full Name \_\_\_\_\_  
(First) \_\_\_\_\_ (M.I.) \_\_\_\_\_ (Last) \_\_\_\_\_ (Citizen of) \_\_\_\_\_ (Birthdate) \_\_\_\_\_

Please fill in both addresses and CHECK THE ONE TO WHICH YOUR MAIL SHOULD BE ADDRESSED.

BUSINESS: Company Name and Division: \_\_\_\_\_

Position \_\_\_\_\_

Address \_\_\_\_\_ City \_\_\_\_\_ State \_\_\_\_\_ Zip Code \_\_\_\_\_

HOME: Address \_\_\_\_\_ City \_\_\_\_\_ State \_\_\_\_\_ Zip Code \_\_\_\_\_

**REFERENCES** The By-Laws require the names of three references who are familiar with your work. One of them should be a member of the Society. Assistance in providing member-references, when needed, will be given on request.

1. \_\_\_\_\_ Address \_\_\_\_\_
2. \_\_\_\_\_ Address \_\_\_\_\_
3. \_\_\_\_\_ Address \_\_\_\_\_

**STATEMENT OF COLLEGE WORK**

Years Attended	Institution	Major and Minor	Degree	Experience Credits See reverse side
From _____ To _____				
				Total Education Experience Credits

**RECORD OF QUALIFYING EXPERIENCE IN PLASTICS**

Dates	Give your title, name and location of employer, and name of immediate superior for each position. List in chronological order. Describe duties fully and state briefly any important engineering work you have done in each position. If space is not sufficient, use a separate sheet.	Time in years and months
From _____ To _____ Mo. Yr. Mo. Yr.		

I certify that the statements made in this application are correct. I agree, if elected, to be governed by the Constitution and By-Laws of the Society, and to promote the objective of the Society.

Total qualifying years of experience.

Total education and qualifying experience credits.

**NATIONAL CREDENTIALS COMMITTEE USE ONLY**

Approved (Signature)

Date

Approved (Signature)

Date

Date of Application

Signature in ink.

# COMPLETING THE APPLICATION

**Grade of Membership . . .**  
 Membership grades are based on experience credits which are earned as follows:

1. Experience credits earned for education.
  - Doctorate in science or engineering subject: **6 credits**
  - Masters in science or engineering subject: **5 credits**
  - Bachelors in science or engineering subject: **4 credits**
  - Other degree in non-science or non-engineering subject: **2 credits**

Maximum credits allowable for education shall be six (6).

When filling in the "Statement of College Work" on the reverse side of this application, please place the corresponding number of credits earned in the right-hand column.

2. Experience credits for qualifying experience in plastics or plastics engineering are earned at the rate of one (1) per year, e.g. 5½ years of qualifying experience = 5½ credits. Please detail carefully the engineering skill required for each position to help the Credentials Committee judge experience as "qualifying."

When filling in the "Record of Qualifying Experience in Plastics" on the reverse side, please place the amount of time spent in each position (in years and months) in the right-hand column.

When you have determined the number of credits which you believe you have earned consult the following membership grade requirements. Indicate on the reverse side the grade of membership for which you believe you are qualified.

## THIS PORTION MUST BE COMPLETED FOR PROCESSING OF YOUR APPLICATION.

Please check off the principal activity of your company under either Manufacturing or Non-Manufacturing.

# MEMBERSHIP APPLICATION



## SOCIETY OF PLASTICS ENGINEERS, INC.

**656 West Putnam Avenue  
Greenwich, Connecticut 06830**

### SPE SECTIONS

1. <input type="checkbox"/> Electrical & Electronic Machinery, Equipment & Appliances	NORTHERN INDIANA
2. <input type="checkbox"/> Motor Vehicles and Equipment	NORTHWEST PENNSYLVANIA
3. <input type="checkbox"/> Transportation Equipment (except Motor Vehicles)	OMAHA
4. <input type="checkbox"/> Professional, Scientific and Controlling Instruments, Photographic & Optical Goods, Clocks	ONTARIO
5. <input type="checkbox"/> Iron, Steel & Nonferrous Metals & Machinery (except Plastic & Electrical Machinery)	PACIFIC NORTHWEST
6. <input type="checkbox"/> Fabricated Metal Products and Housewares	PALISADES
7. <input type="checkbox"/> Finished Apparel Products	PHILADELPHIA
8. <input type="checkbox"/> Food and Tobacco Products	PIONEER VALLEY
9. <input type="checkbox"/> Toilet Preparations, Drugs and Insecticides	PITTSBURGH
10. <input type="checkbox"/> Paints, Varnishes, and Industrial Chemicals (except Plastic Raw Materials)	QUEBEC
11. <input type="checkbox"/> Petroleum, Coal, Rubber, Stone and Glass Products	ROCHESTER
12. <input type="checkbox"/> Musical Instruments, Toys, Sporting Goods, Athletic Goods, Ordnance & Smokers' Supplies	ROCKY MOUNTAIN
13. <input type="checkbox"/> Jewelry and Fashion Accessories	ST. LOUIS
14. <input type="checkbox"/> Furniture and Finished Wood Products	EAST CENTRAL ILLINOIS
15. <input type="checkbox"/> Leather and Leather Products	SOUTHEASTERN OHIO
16. <input type="checkbox"/> MANUFACTURING, other than above. Please specify —	SOUTHERN
17. <input type="checkbox"/> Plastics Custom Molders, Extruders, Laminators, and Fabricators	SOUTHERN CALIFORNIA
18. <input type="checkbox"/> Plastic Materials	SOUTHEASTERN NEW ENGLAND
19. <input type="checkbox"/> Producers and Processors of Textiles, Lumber, Paper, Oils, Dyes, Chemicals, etc. used in Manufacture of Plastics	FLORIDA
20. <input type="checkbox"/> Plastic Machinery	GOLDEN GATE
	HUDSON-MOHAWK
	JAPAN
	KANSAS CITY
	KENTUCKIANA
	MIAMI VALLEY
	MID-MICHIGAN
	MILWAUKEE
	MONTERREY
	NEW YORK
	NEWARK
	WESTERN NEW ENGLAND
	NORTH TEXAS
	NON-SECTION

### NON-MANUFACTURING

21.  Government: Federal, State, Municipal and Foreign;
22.  Officers of the Armed Forces
23.  Advertising Agencies, Sales Consultants and Sales Engineers
24.  Libraries, Schools, Colleges and Trade Associations
25.  Consultants and Research Organizations, Architects, Engineers, Designers, Chemists
26.  Transportation Operating Companies
27.  Exporters, Importers, Distributors, Jobbers, Wholesalers and Manufacturers' Agents
28.  Doctors, Lawyers and other Professionals
29.  NON-MANUFACTURING, other than above. Please specify \_\_\_\_\_
30.  Packaging & Containers
31.  Aerospace
32.  Construction Materials

### REQUIREMENTS

GRADE	REQUIREMENTS
Senior Member	Minimum of twelve (12) experience credits and maintained continuous membership in the Society for a minimum of two (2) years.
Member	Minimum of six (6) experience credits
Affiliate Member	Less than six (6) experience credits
Student Member	Regularly enrolled student (full- or part-time) in a course of study in plastics and between the ages of 16 years and 26 years, inclusive.